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ANTENNA SYSTEM REQUIREMENTS REPORT
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SHUTTLE MILLIMETER WAVE COMMUNICATIONS EXPERIMENT ANTENNA SYSTEM DEVELOPMENT

MARCH 1978

PREPARED FOR: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771
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ANTENNA DEPARTMENT
RADAR SYSTEMS GROUP

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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Greenbelt, Maryland 20771

Contract NAS5-24277

Engineering Division
RADAR SYSTEMS GROUP
Hughes Aircraft Company • Culver City, California

FOREWORD

The Hughes Aircraft Company is pleased to submit this antenna system requirements report documenting the results of the "Shuttle Millimeter Wave Communications Experiment Antenna System Development." The prime object of this contract is to define the antenna system for the GSFC Space Shuttle MWCE. The primary objective of the MWCE is to evaluate wideband communications techniques for space applications in the millimeter wavelength band, 20 GHz (downlink) and 30 GHz (uplink). The Hughes personnel who participated in this program include: W.H. Kummer, Program Manager, S.R. Kerner, J.R. Miller, A.F. Seaton, and W.D. Townsend.

The Technical Officer for NASA Goddard Space Flight Center is Dr. L.J. Ippolito.

CONTENTS

LIST OF ILLUSTRATIONS

PAGE VI INTENTIONALLY BLANK

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

1. INTRODUCTION

Because of the crowding of the microwave spectrum, the use of higher radio frequencies has been advocated for some time as a means by which the congestion could be relieved. There has been only limited use of frequencies above 16 GHz because of certain inherent limitations in the propagation path and in the needed communication equipment. These limitations include the severe path attenuation due to rain and increased depolarization, higher antenna pointing requirements, a higher receiver noise figure, and less efficient transmitters.

For some time now, experiments have been devised for quantification of the propagation phenomena associated with the millimeter wavelength region, with the purpose of tailored system designs that could maximize the reliability of the communication links.

This particular MWCE* experiment has a threefold purpose:

1. To evaluate propagation phenomena (beacon mode).
2. To evaluate wideband data transmission in a transponder mode (transponder mode)
3. To provide a wideband link for data transfer to the TDRSS (Spacelab mode)

The three modes are illustrated in Figure 1-1.

The beacon mode would be used for the propagation experiments. In the transponder mode, earth stations communicate with each other with the Shuttle serving as a relay. In the Spacelab mode, two spatial links can

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*"Proposal for a Millimeter Wave Communications Experiment (MWCE) Volume I, Investigation and Technical Plan," Communications and Navigation Division, NASA/GSFE, May 1977.

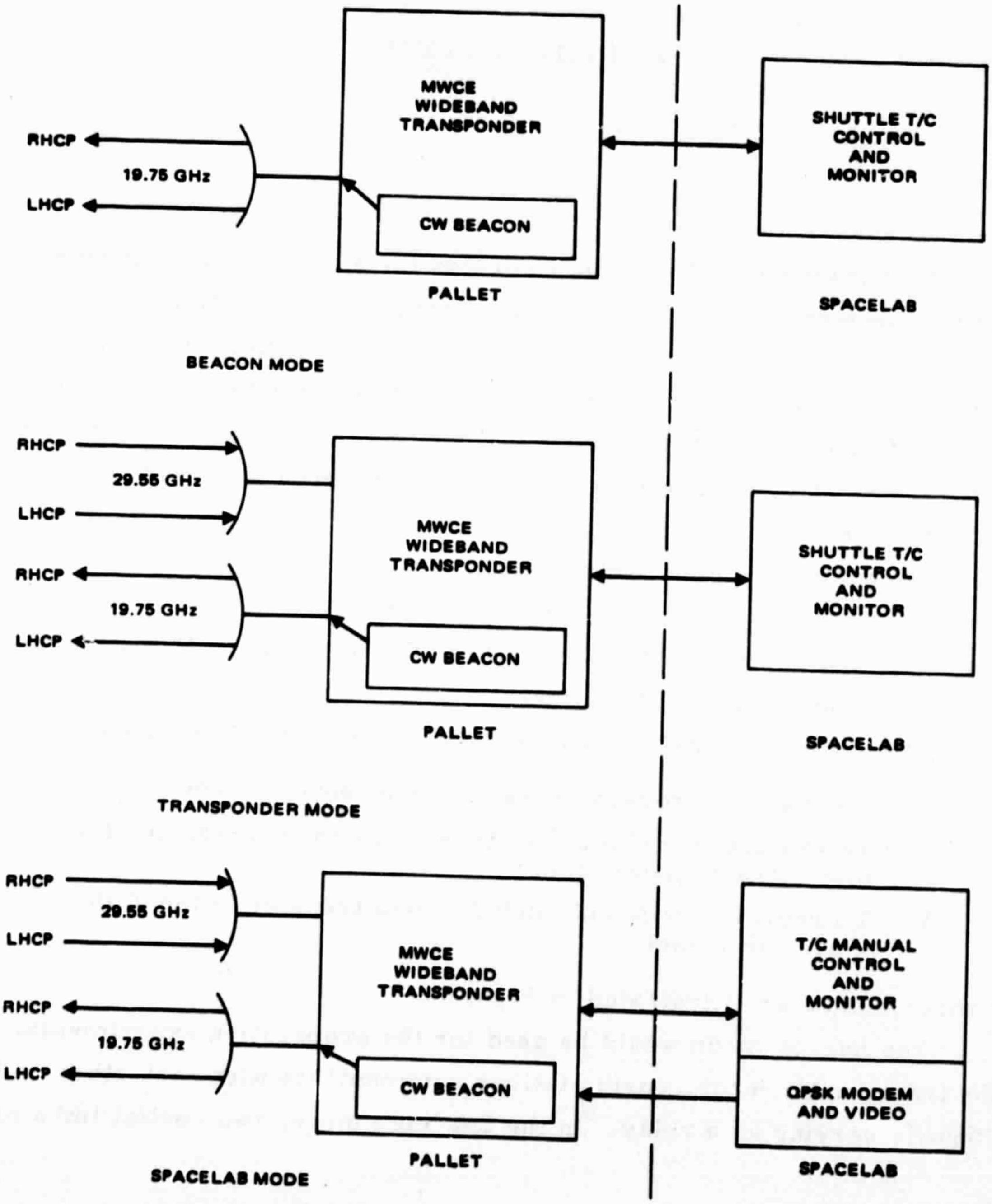

Figure 1-1. MWCE modes of operation.

be established if separate transmitting/receiving antennas and associated beam-steering controls are employed. Thus data can be passed simultaneously by the Shuttle to the TDRSS from widely separated ground stations.

Since the inception of the experiment, the antenna system has been identified as the critical subsystem; other subsystems may be integrated from state-of-the-art components similar to those used on the ATS-6 missions. The Millimeter-Wave Communications Experiment has undergone many changes in design and implementation since the initial Hughes study in 1973 for a 10 by 10 meter square electronically steered phased array. In spite of the alterations, the basic goal of the experiment, to extend the data base for earth-satellite communications, has remained unchanged.

Because of the distance (400 km) and variable angle between the low-orbiting Shuttle and the ground station, an antenna pattern that results in a fairly constant signal-to-noise ratio for the communication system is desired. (See Figure 2-1). The area under the bowl-shaped curve of this pattern gives a directivity greater than that obtainable from one physically realizable antenna, so it is necessary to scan an antenna having a pattern which is less than omnidirectional in azimuth.

Several possible approaches were considered, studied, and evaluated with respect to system requirements in terms of electrical performance, reliability, technical risk and cost. Three types of radiating apertures were considered:

1. A planar slot array system to give the shaped pattern.
2. A shaped paraboloidal reflector to give the shaped pattern.
3. A paraboloidal reflector to give a far-field pencil beam.

Three types of scanning designs were investigated:

1. A set of apertures scanned electronically or electromechanically in one plane.
2. One aperture mechanically scanned in azimuth.
3. A paraboloidal reflector scanned with an existing two-axis positioner.

The results of this phase of the program are given in the Antenna Feasibility Design Study Report (HAC Report No. P77-535R, HAC Ref. No. E0522, Dept. Ref. No. 2753/1242). It was found that there was no one system best in all areas. The two-axis positioner with the paraboloidal reflector was the most versatile and offers a significant increase in achievable gain over the other systems. The one-axis positioner with the shaped reflector achieved the desired performance with a simpler gimbal. The estimated costs for all the systems was about the same. Two antenna systems were selected for design. These are:

1. A paraboloidal reflector to give a far-field pencil beam scanned with an existing two-axis positioner.*
2. A shaped paraboloidal reflector to give a shaped elevation pattern, and mechanically scanned in azimuth.

This report discusses the design of these antenna systems, including electrical and mechanical subsystem performance, specifications, size, weight, and overall antenna system definition.

The operation of the MWCE antenna sys em may be considered in terms of its several component systems:

1. A waveguide network which separates the 20 and 30 GHz signals and selects one of the circularly polarized field components at each frequency.
2. A conical corrugated feed horn which provides equal beamwidths in both the E- and H-planes, and for both frequencies.
3. A dish reflector which collimates the r-f energy on transmission and reception between the spacecraft and ground terminals.
4. A gimbal system which positions the reflector. This will be a two-axis system for the Cassegrain-feed paraboloidal dish and a one-axis system for the focal-point-feed shaped dish.

The detailed designs were discussed in the Antenna System Design and Definition Report (HAC Report No. P78-103 HAC Ref. No. EO522, Dept. Ref. No. 2753/1360). In this report these designs will be translated into detailed

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*The two-axis positioner is being developed on Rockwell International PO. M7J3XMB-483139D for the Ku-Band Radar and Communications Equipment for the Space Shuttle Orbiter Vehicle.

antenna requirements which include the subsystems discussed above. Estimated fabrication costs and development time will be provided in a separate volume. The system specifications are discussed in the next section.

2. ANTENNA SYSTEM SPECIFICATIONS

The antenna specifications are defined in Table 2-1 and Figure 2-1. The figure shows the minimum one-way gain required for equal antenna gains in the receive and transmit frequency bands.

Beacuse both antenna systems considered here are rotatable in azimuth, this gain curve need not be symmetric about the boresight direction. The antenna effectively has a 140 degree (±70 degrees) field of view as shown in Table 2-1.

TABLE 2-1. ANTENNA PARAMETERS

1. Operational Frequencies:

Receiving	29.75 GHz ±250 MHz
Transmitting	19.95 GHz ±250 MHz

2. Simultaneous Operation on Transmit and Receive
3. Field of View: 70 degrees
4. Polarization: Two senses of circular polarization at each frequency. Switchable to allow selection of one sense at each frequency
5. Axial Ratios: TBD
6. Beam Motion: 3 degrees/minute
7. Minimum 3 dB Beamwidth: 1.0 degrees

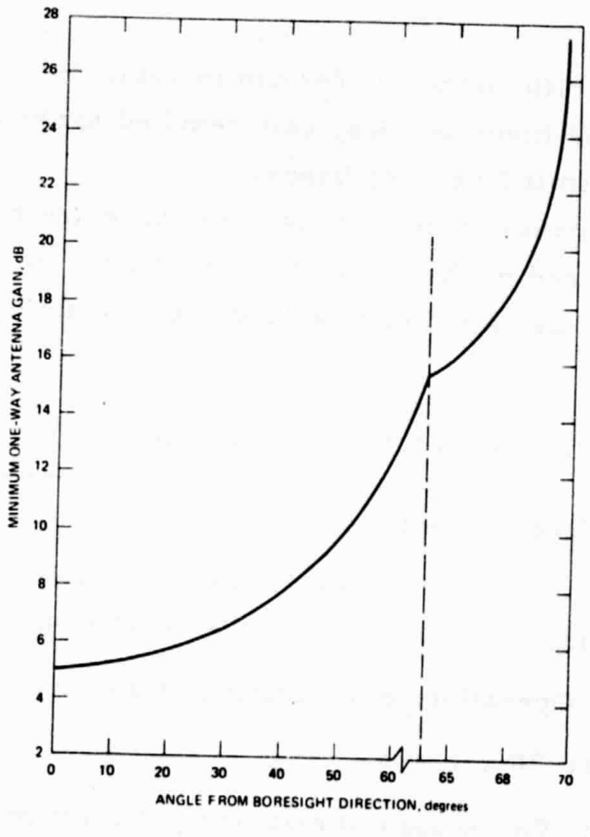

Figure 2-1. Antenna gain contour.

3. WAVEGUIDE CIRCUITRY

The waveguide circuitry connected to the horn separates the 30 GHz received and 20 GHz transmitted signals into left- and right-circularly polarized signals and allows for the selection of one sense of circular polarization at each frequency. These functions are accomplished by three major components: (1) an orthomode transducer, (2) a waveguide diplexer and (3) a pair of SPDT solenoid actuated waveguide switches. The layout of this network is shown schematically in Figure 3-1. The actual system is shown in Figure 3-2.

There are four different waveguides used in this system: circular guide supporting the TE_{11} dominant modes, WR 34 rectangular waveguide for both 20 and 30 GHz signals, WR 42 guide for the 20 GHz transmitting signals and WR 28 for the 30 GHz receiving signals. Tables 3-1 and 3-2 list the characteristics of these waveguides. It should be noted that the circular guide can support higher order modes. It is believed that these will not be generated with the present configuration.

The orthomode transducer serves to separate the 20 and 30 GHz signals into two linear orthogonal polarizations. The device uses a gradual transition from the TE_{11} circular guide-to-finline to separate the orthogonal TE_{11} modes. The transformed vertical TE_{11} mode is coupled out of the main line via the finline into WR 34 rectangular waveguide as shown in Figure 3-3. The horizontal component of the TE_{11} mode is coupled to another WR 34 waveguide through a circular-to-rectangular tapered transition. The isolation between the orthogonal TE_{11} modes is only a function of the accuracy with which symmetry can be maintained in the transducer. The VSWR is a function of the TE_{11}-to-finline taper and TE_{11}-to-WR 34 transition. A

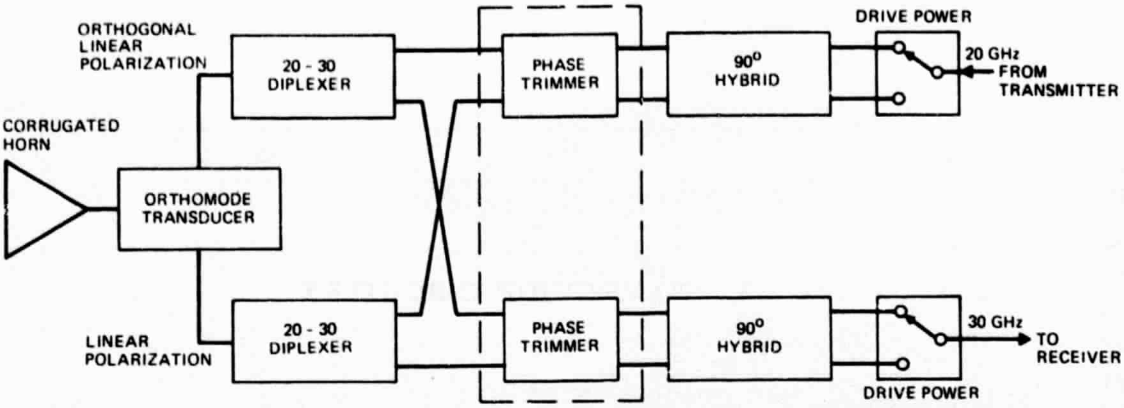

Figure 3-1. Waveguide network for dual channel horn system.

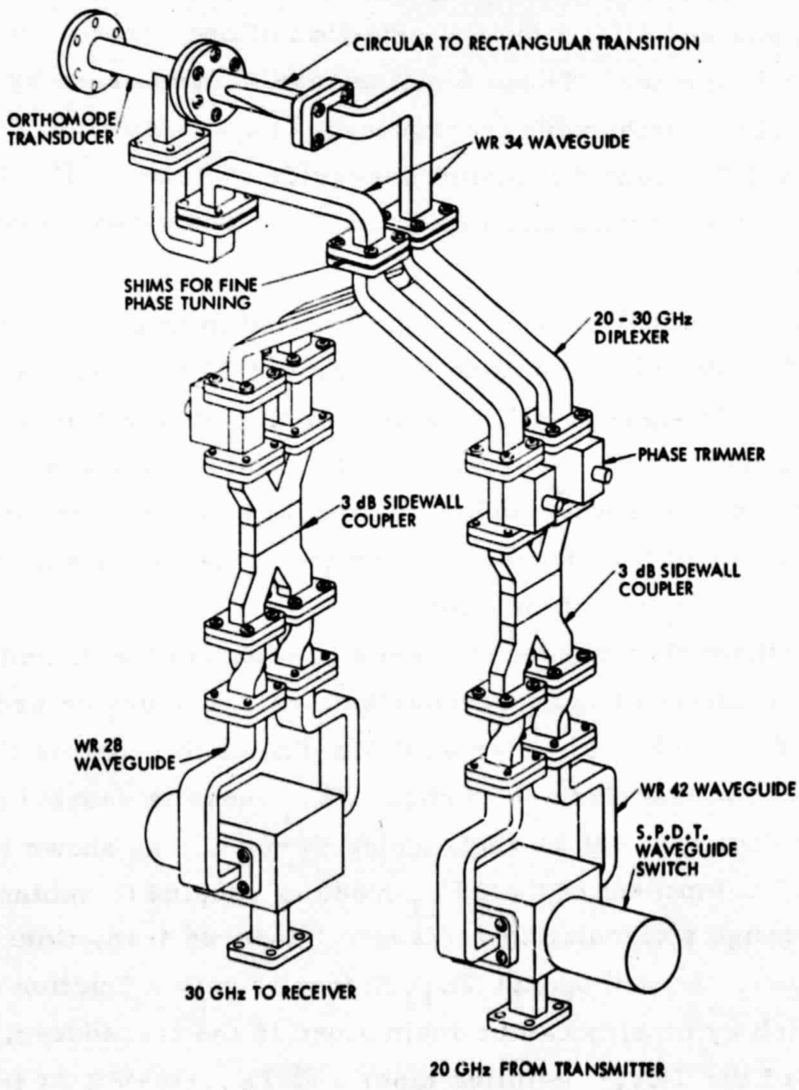

Figure 3-2. Waveguide feed circuitry.

TABLE 3-1. CHARACTERISTICS OF RECTANGULAR WAVEGUIDES

Waveguide Designation	WR-42 RG-53/U	WR-34	WR-28 RG-96/U
Frequency of Operation	19.95 ±0.25 GHz	20 to 30 GHz	29.75 ±0.25 GHz
Cut-off Frequency*	14.051 GHz	17.328 GHz	21.077 GHz
Inside Dimensions	0.420 x 0.170 inches 10.67 x 4.32 mm	0.340 x 0.170 inches 8.64 x 4.32 mm	0.280 x 0.140 inches 7.11 x 3.56 mm
Attenuation (Measured)	0.73 dB/m. at 20 GHz	0.87 dB/m. at 26 GHz (Est.)	1.25 dB/m. at 30 GHz

*For dominant mode

TABLE 3-2. CHARACTERISTICS OF CIRCULAR WAVEGUIDE

Dimensions	1.12 cm Inside Diameter
<u>Modes</u>	<u>Cut-Off Frequency, GHz</u>
TE_{11} (dominant mode)	15.7
TM_{01}	20.6
TE_{21}	26.1
TM_{11}/TE_{01}	32.7
TE_{11} Attenuation	Theor. — 0.3 dB/meter at 20 GHz
TE_{11} Guide Wavelength	1.66 λ_o at 19.7 GHz 1.17 λ_o at 30.0 GHz

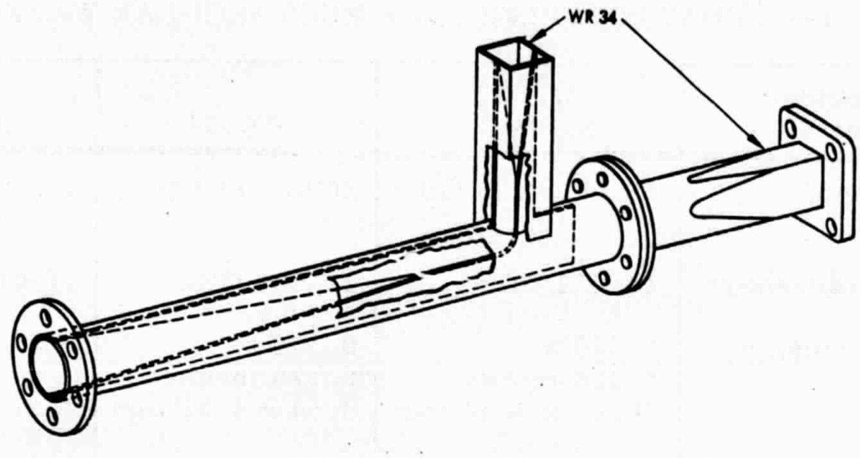

Figure 3-3. Orthomode transducer.

straight TE_{11}-to-finline taper was used, following the original design by Robertson, * who operated his system from 3.75 to 12 GHz. The detailed layout of the pertinent dimensions is shown in Figure 3-4. The loss is estimated to about 0.1 dB.

Through suitable E- and H-plane waveguide bends, the WR 34 waveguides are brought into the same plane. Phase trimmings may be necessary in the lines leading from the finline coupler and rectangular-to-circular transition to the diplexers. The lengths of these lines can be adjusted to give the desired phase difference at one frequency; however, the phase characteristics of the two transitions do not vary identically with frequency. This behavior gives rise to phase deviations which may be sufficient to degrade the axial ratios. This effect can be corrected by inserting a short length of dielectrically loaded line in one branch. The length of the line and the thickness of the dielectric can be varied so that nearly identical phase-frequency characteristics are obtained from the two branches.

*S. D. Robertson, "Recent Advances in Finline Circuits", IRE Trans. MTT, Vol MTT-4, pp 263-267; Oct. 1956.

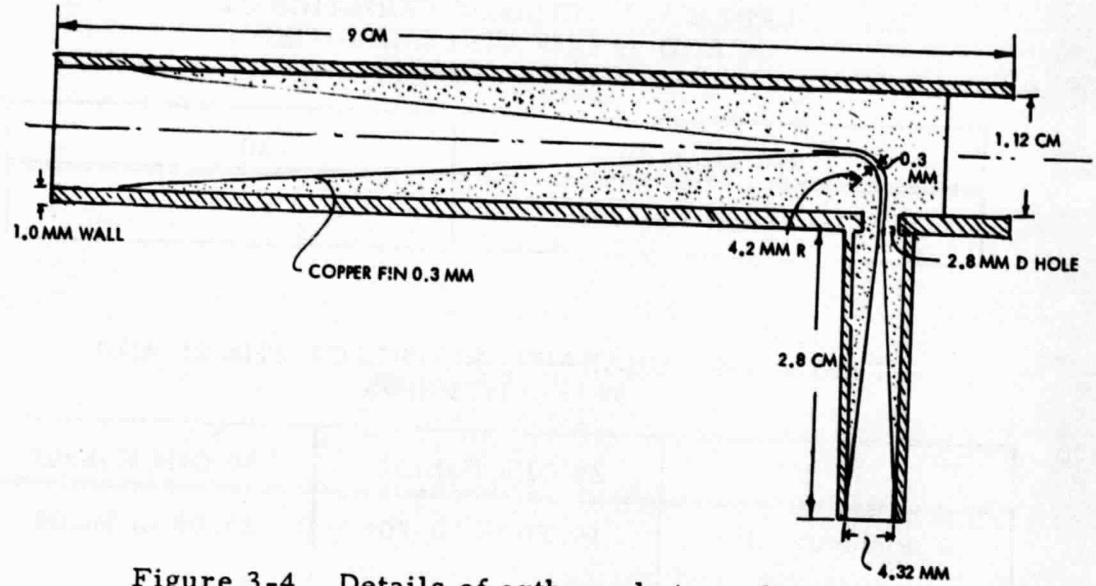

Figure 3-4. Details of orthomode transducer.

Two identical diplexers consisting of branching filters serve to seperate the 20 and 30 GHz signals. The specifications of the diplexers are given in Table 3-3. An example of a suitable unit would be the MDL model 34D2P19.

In each channel a 90 degree hybrid is used to reconstitute the circularly polarized waves. The specifications for the two hybrids are given in Table 3-4. A phase trimmer is inserted between the output arms of the diplexer and each hybrid. The trimmers consist of thin slabs of dielectric inserted in slots along the center of the guide. Phase deviations which arise from minor differences in waveguide dimensions may be compensated by adjustment of the phase timmers. In this manner the axial ratios of the complete system can be minimized for each frequency band.

Two single-pole double-throw switches are connected through suitable waveguide bends to permit selection of either sense of polarization at each frequency. The characteristics of a suitable switch are listed in Table 3-5.

The layout of the components has been made and is shown in Figure 3-2. Depending on the specific packaging requirements dictated by the antenna, the transmitter, the receiver, and gimbal configurations, changes can be made in the type and length of the waveguide sections as long as equal line lengths are maintained in the appropriate parts of the system. Once a

TABLE 3-3. CHARACTERISTICS OF 20 AND 30 GHZ DIPLEXER – MDL MODEL 34D2P19

Isolation dB	>30
Insertion Loss, dB	<1

TABLE 3-4. CHARACTERISTICS OF THE 20 AND 30 GHz HYBRIDS

	20 GHz Hybrid	30 GHz Hybrid
Frequency, GHz	19.70 to 20.20	29.50 to 30.00
Coupling, dB	3.0	3.0
Balance, dB	±0.25	±0.25
Isolation, dB	30 minimum	30 minimum
Loss, dB	0.10 maximum	0.15 maximum
Model MDL	42HS32	28HSA22

TABLE 3-5. CHARACTERISTICS OF WAVEGUIDE SWITCHES

Frequency (Nominal) GHz	20	30
Isolation, dB	60	60
Loss, dB	0.2	0.3
VSWR Maximum	1.15 (18 to 26.5 GHz)	1.15 (26.5 to 40 GHz)
Switching Time	← 100 ms →	
Drive Power	← 28 V at 1.0 amp →	

specific antenna-positioner combination has been selected any necessary minor design changes can be made. The characteristics of the overall feed system are summarized in Table 3-6.

The waveguide circuitry specifications are listed in Table 3-7.

TABLE 3-6. SUMMARY OF WAVEGUIDE CIRCUITRY

Weight, kg	1.7 (3.8 pounds)
Loss, dB	0.9
Input VSWR	1.5:1
Channel Isolation between 20 and 30 GHz, dB	>30

TABLE 3-7. WAVEGUIDE CIRCUITRY SPECIFICATIONS

Input from Antenna:

Circular Waveguide – Two orthogonal TE_{11} modes operating at 20 and 30 GHz with Special Flange mating with Feedhorn

Output: 20 GHz WR 42 waveguide with flange UG596/U
30 GHz WR 28 waveguide with flange UG599/U

Circuitry: To provide Selectable Left Hand and Right Hand Circular Polarization at Both Frequencies

Switching Time: Less than 200 ms

Drive Power: 28 V at 1.0 amp

Control Circuitry: Compatible with other signalling in MWCE experiment (TBD)

Input VSWR: 1.5:1

Maximum Loss including switches, polarizer and filters: 0.9 dB

Isolation between 20 and 30 GHz signals: >30 dB

Maximum Cross-Polarization generated by this Circuitry: 40 dB

Maximum Weight: 1.7 Kg

Specific Packaging Configuration: To be compatible with overall experiment configuration (TBD)

4. FEED HORN DESIGNS

The basic goal of the feed design was to develop a horn capable of giving equal field amplitudes in both the E- and H- planes in order to obtain low axial ratios for the circularly polarized signals. This requirement necessitates the use of small grooves in the flared section of the horn to provide the proper impedance relationships.

A. Cassegrain System Feed Horn Design

Features of the Cassegrain geometry (such as focal length and subreflector size and position) dictated the choice of physical parameters for the horn in the double-axis gimbal system. As shown in Figure 4-1, the initial design for the flared section is to be 2.079 inches long, with a 0.440 inch input diameter and a 1.478 inch inner diameter in the aperture. The flare angle is 14.0 degrees, and the grooves are 0.150 inch deep. The E- and H-plane patterns for this horn are given in Figures 4-2 through 4-5.

B. Shaped Reflector System Feed Horn Design

In the feed design for the shaped paraboloidal reflector system, selection of physical parameters hinged largely on the fact that the shaped reflector subtends a 106 degrees angle at the feed location. The horn in this case is 0.520 inches long, with input and aperture diameters of 0.440 inch and 1.820 inches, respectively. The flare angle is 53.0 degrees, and corrugations are again 0.150 inches deep. The flared section is depicted in Figure 4-6; E- and H- plane patterns are found in Figures 4-7 through 4-10. Because the pattern predicted from the available computer programs may be inaccurate for very large flare angles, it may be necessary to perform several iterations in the development of the experimental model of this horn.

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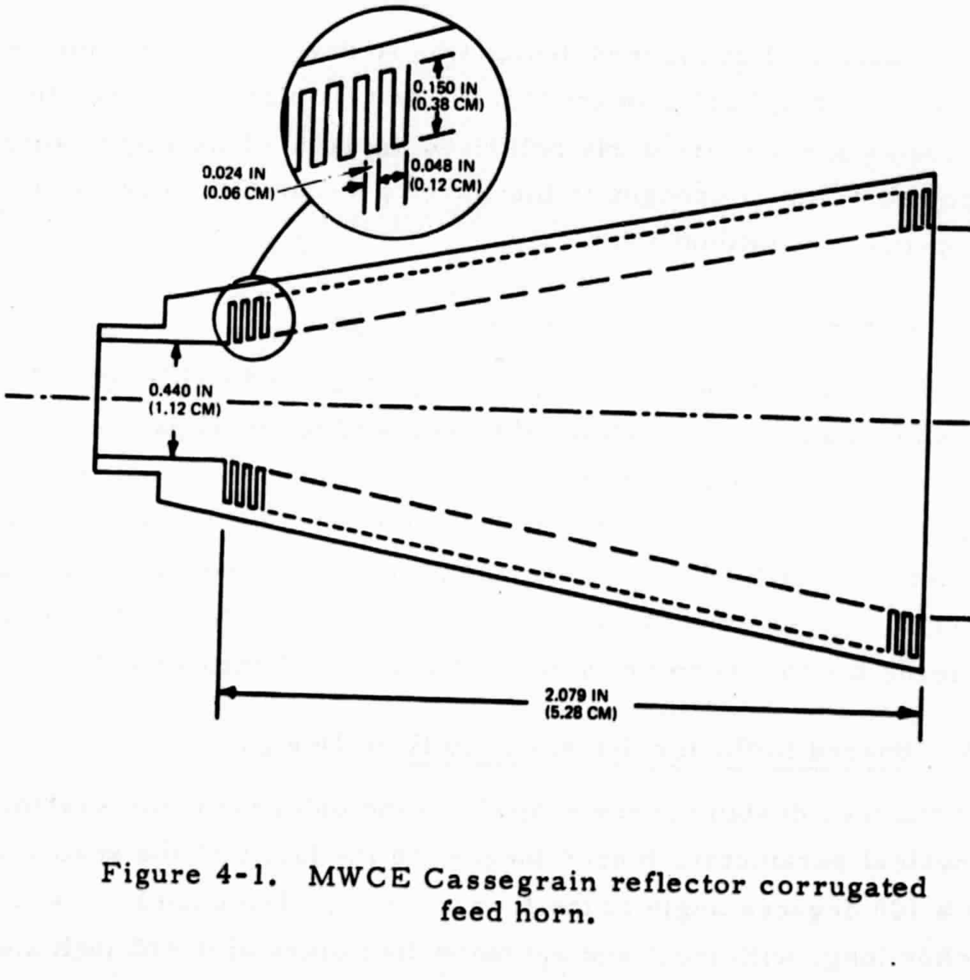

Figure 4-1. MWCE Cassegrain reflector corrugated feed horn.

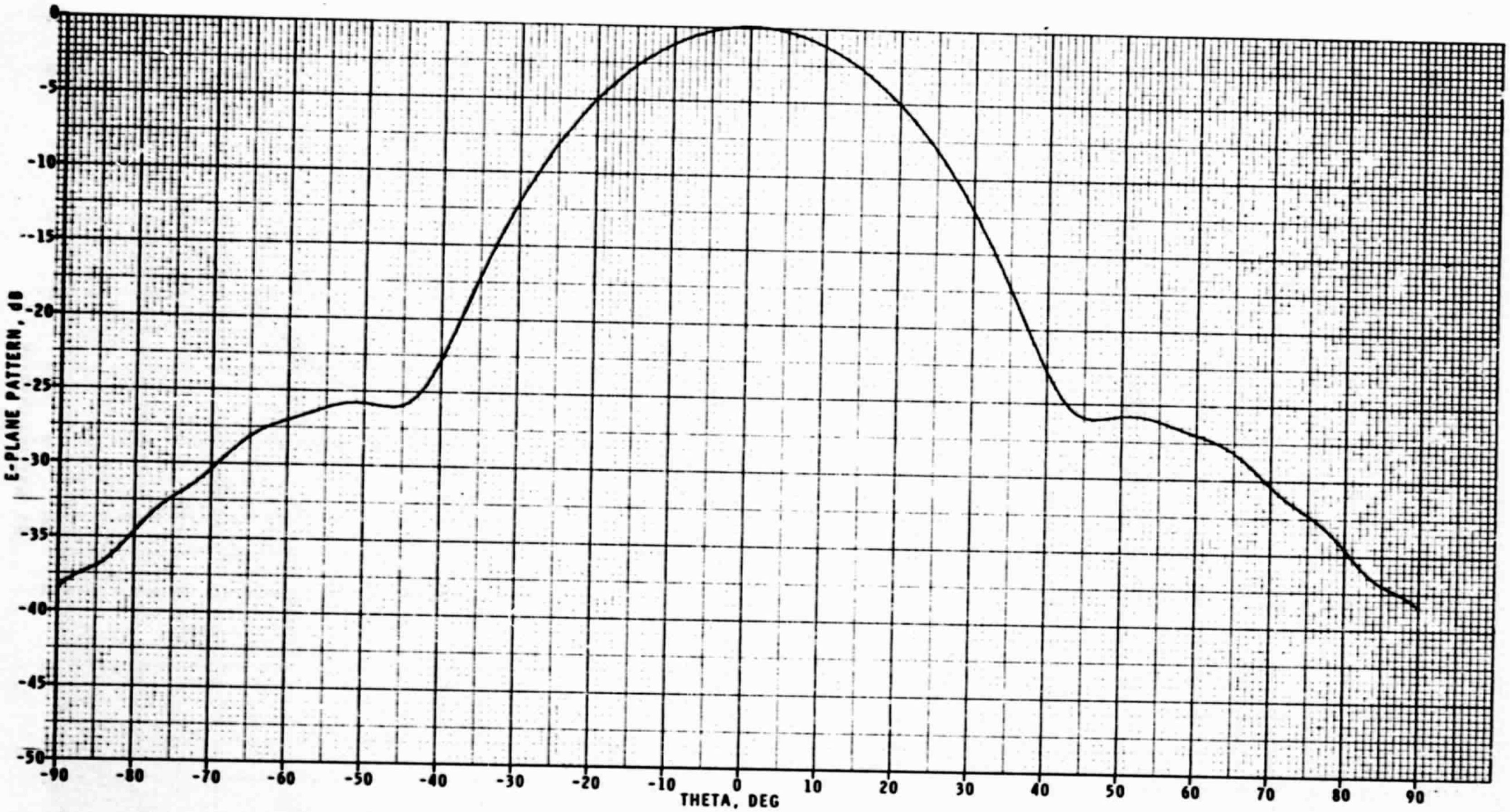

Figure 4-2. E-plane pattern for Cassegrain reflector feed horn (20 GHz).

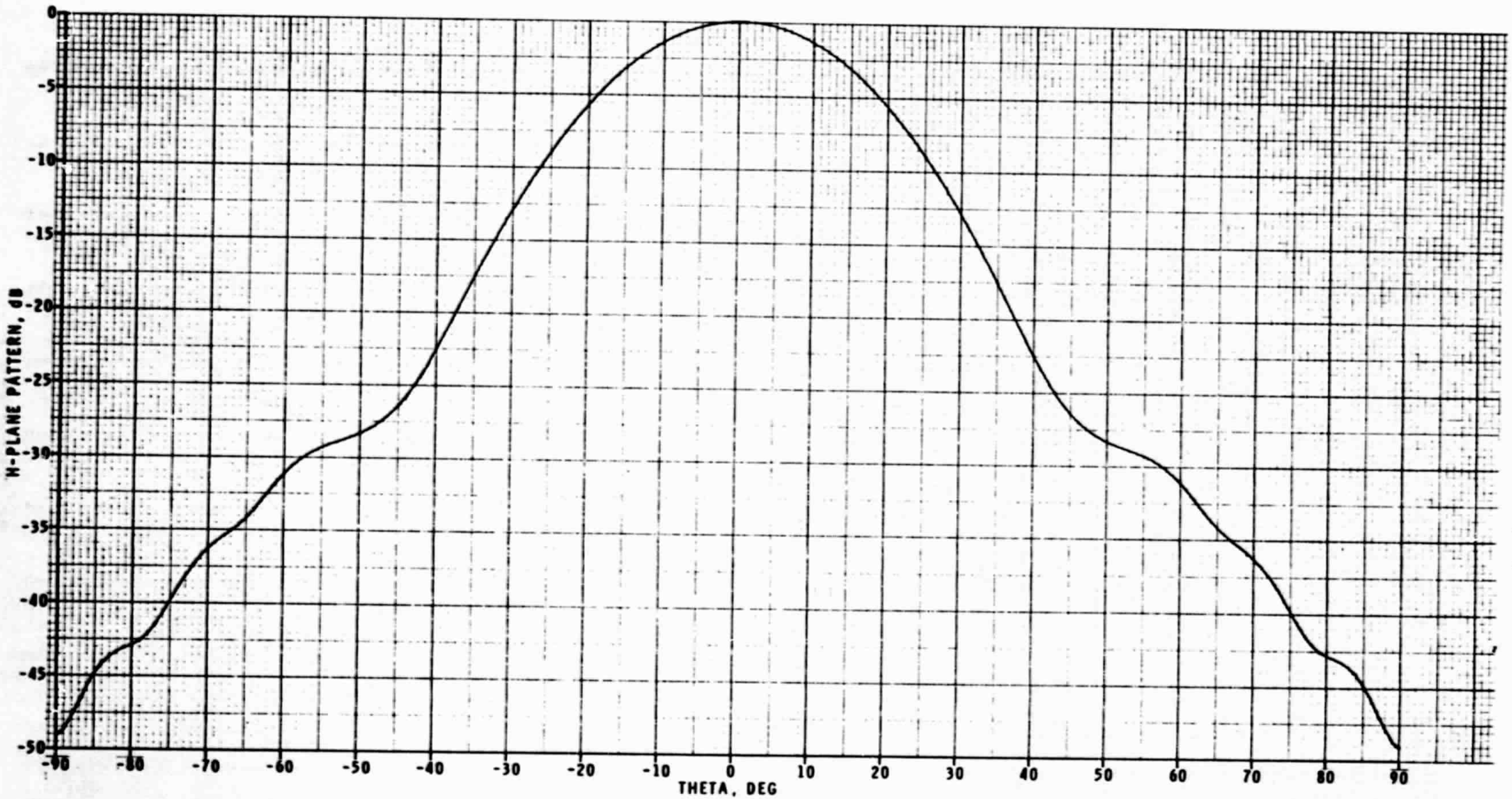

Figure 4-3. H-plane pattern for Cassegrain reflector feed horn (20 GHz).

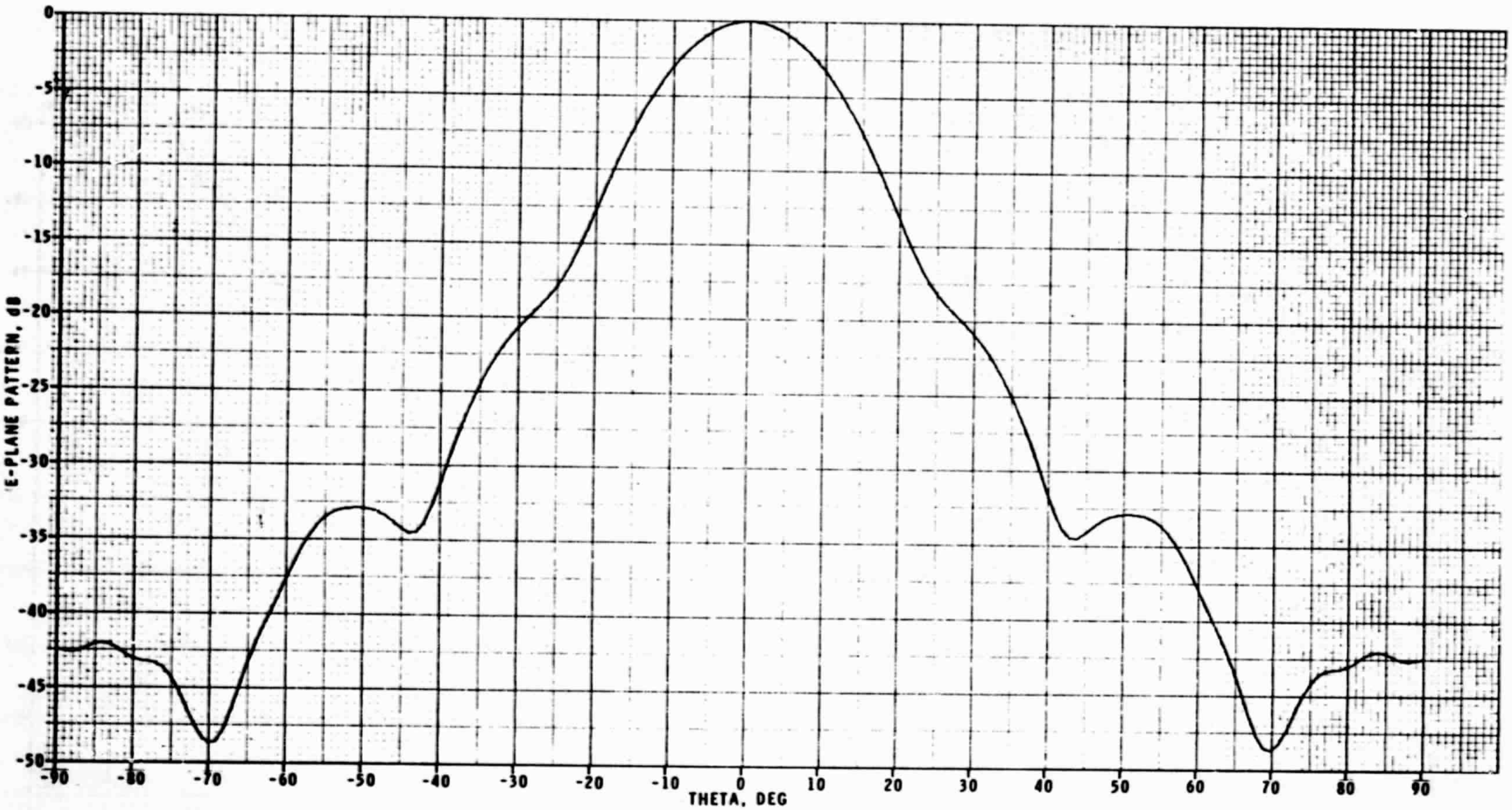

Figure 4-4. E-plane pattern for Cassegrain reflector feed horn (30 GHz).

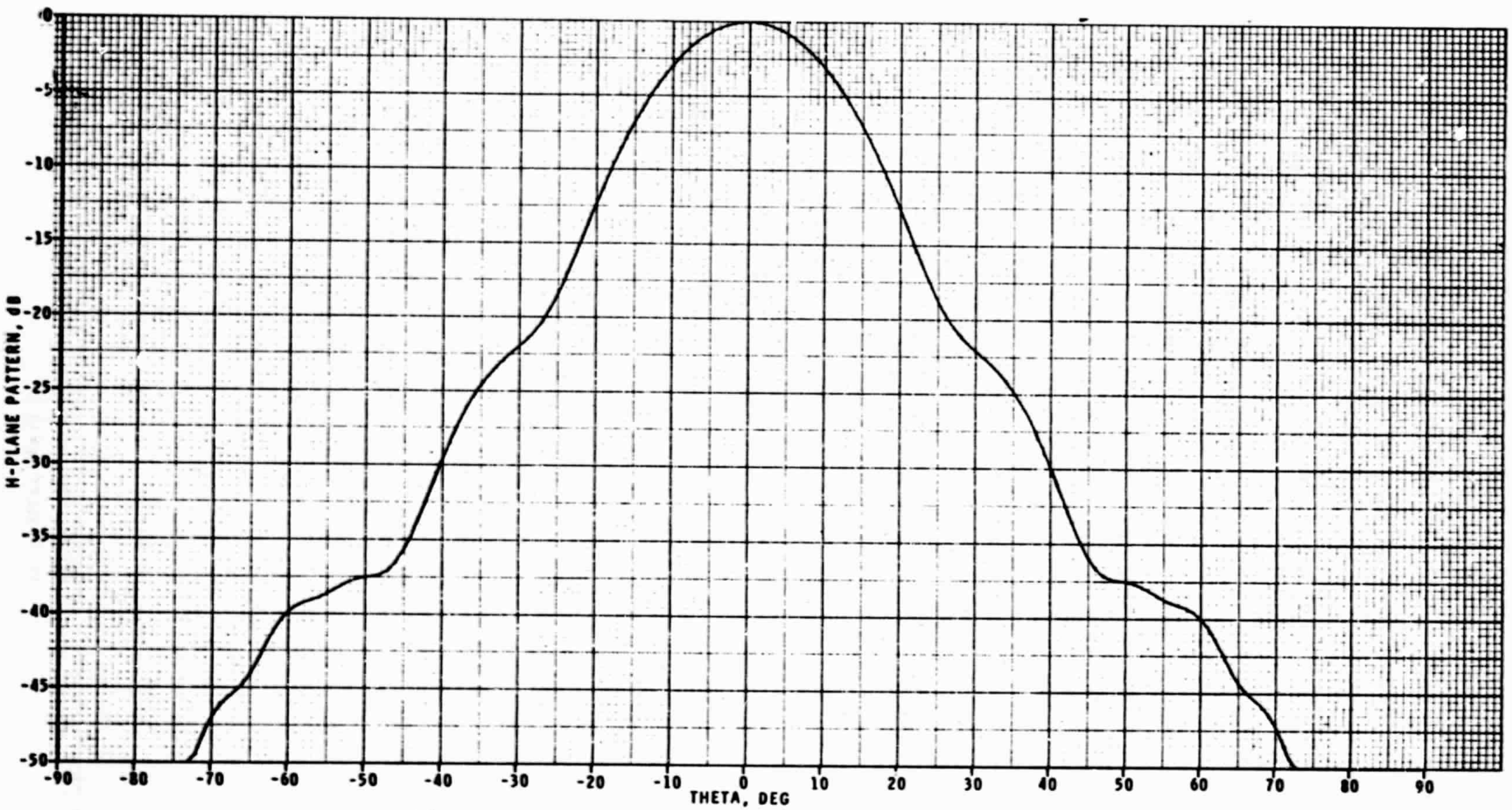

Figure 4-5. H-plane pattern for Cassegrain reflector feed horn (30 GHz).

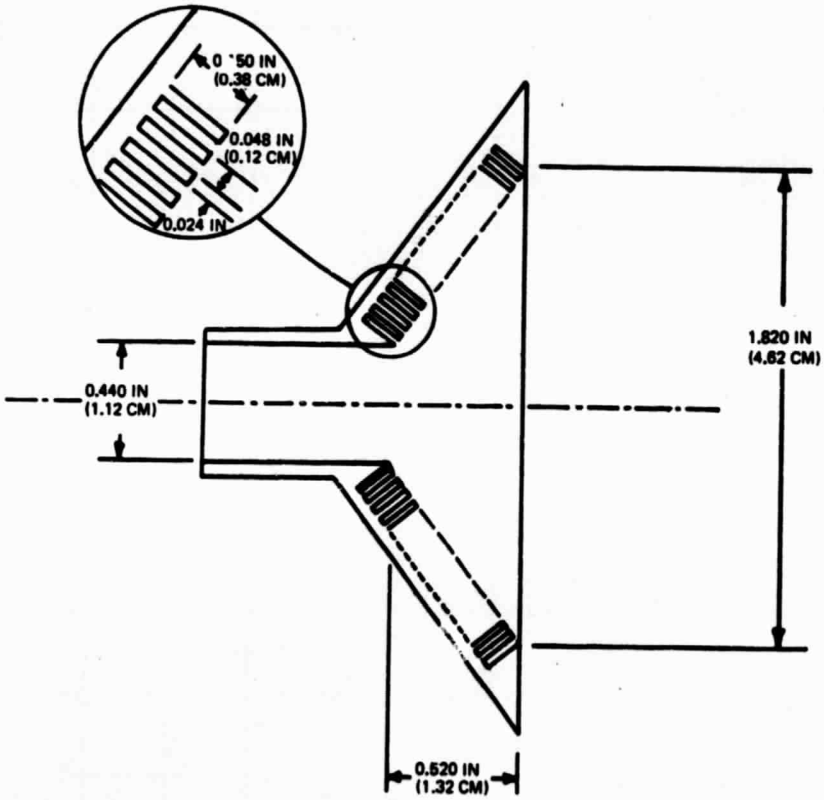

Figure 4-6. MWCE shaped reflector corrugated feed horn.

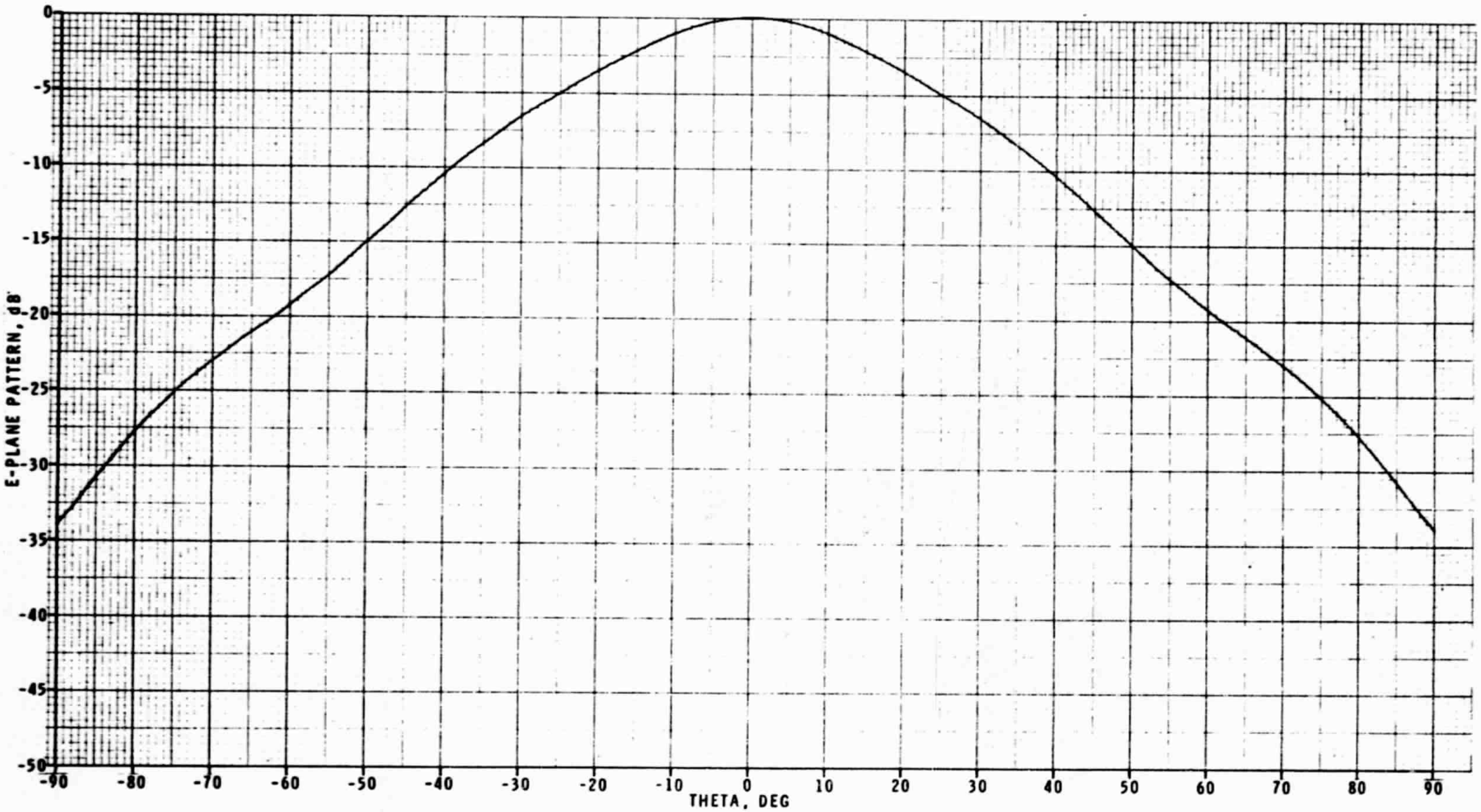

Figure 4-7. E-plane pattern for shaped reflector feed horn (20 GHz).

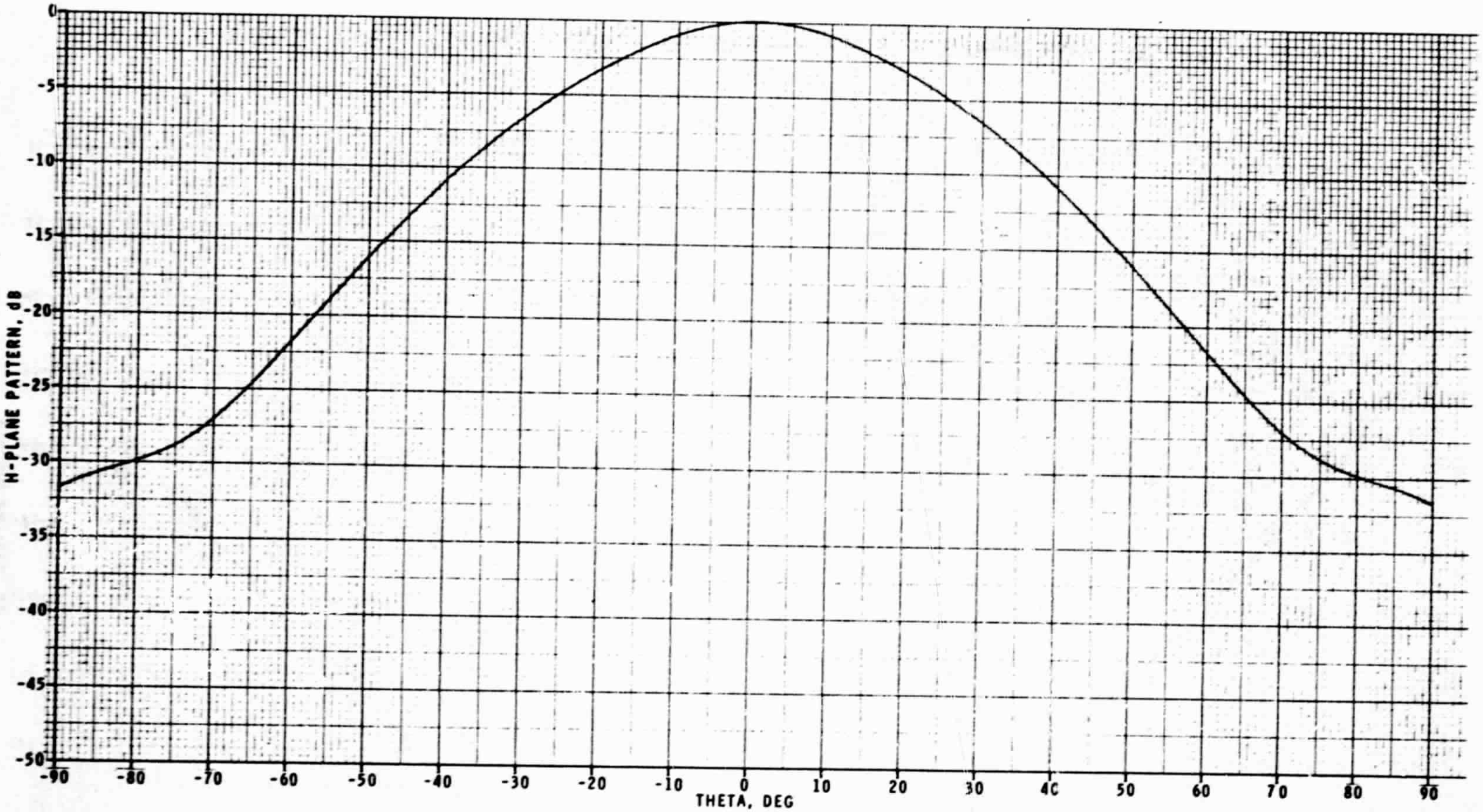

Figure 4-8. H-plane pattern for shaped reflector feed horn (20 GHz).

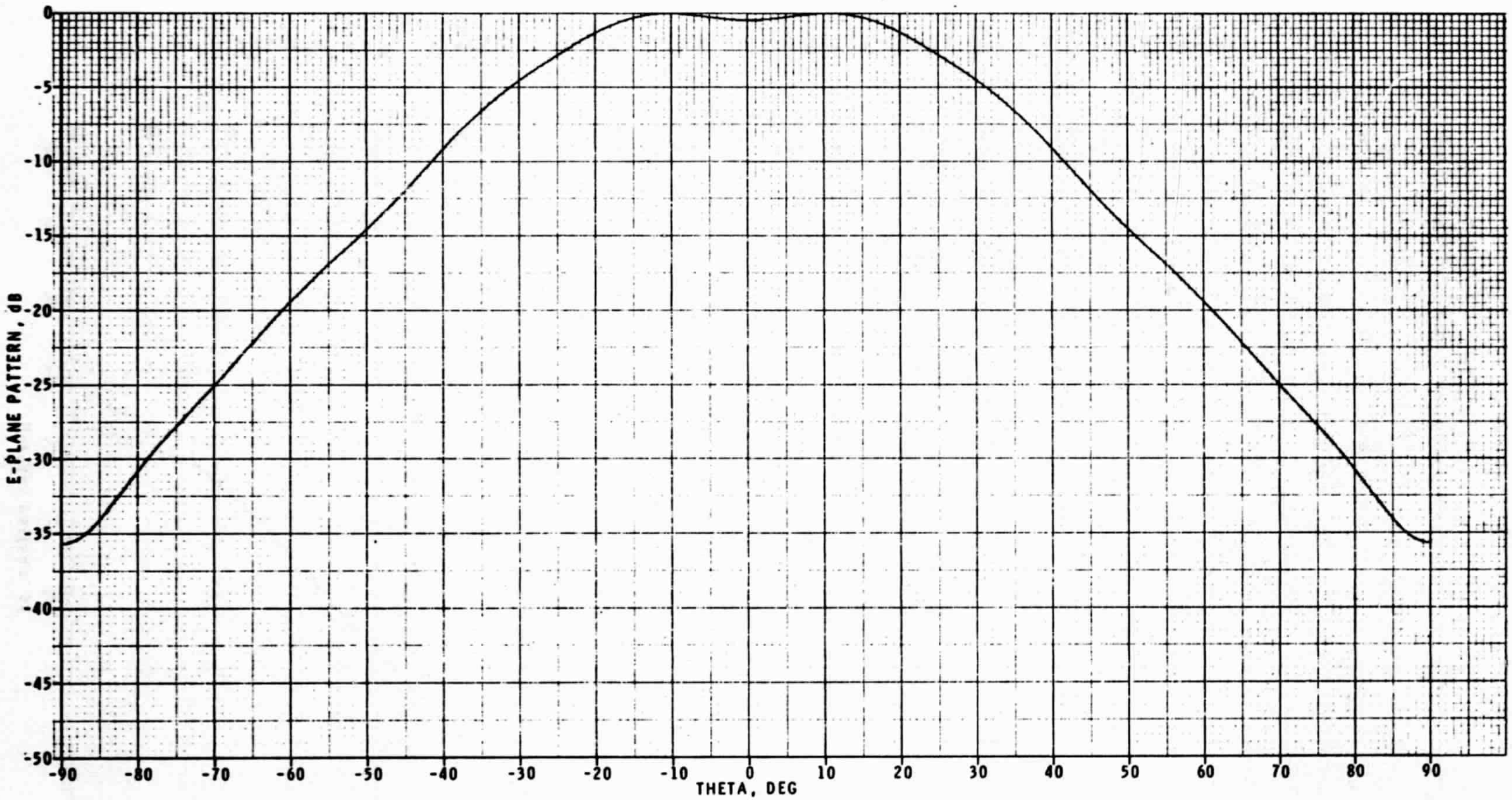

Figure 4-9. E-plane pattern for shaped reflector feed horn (30 GHz).

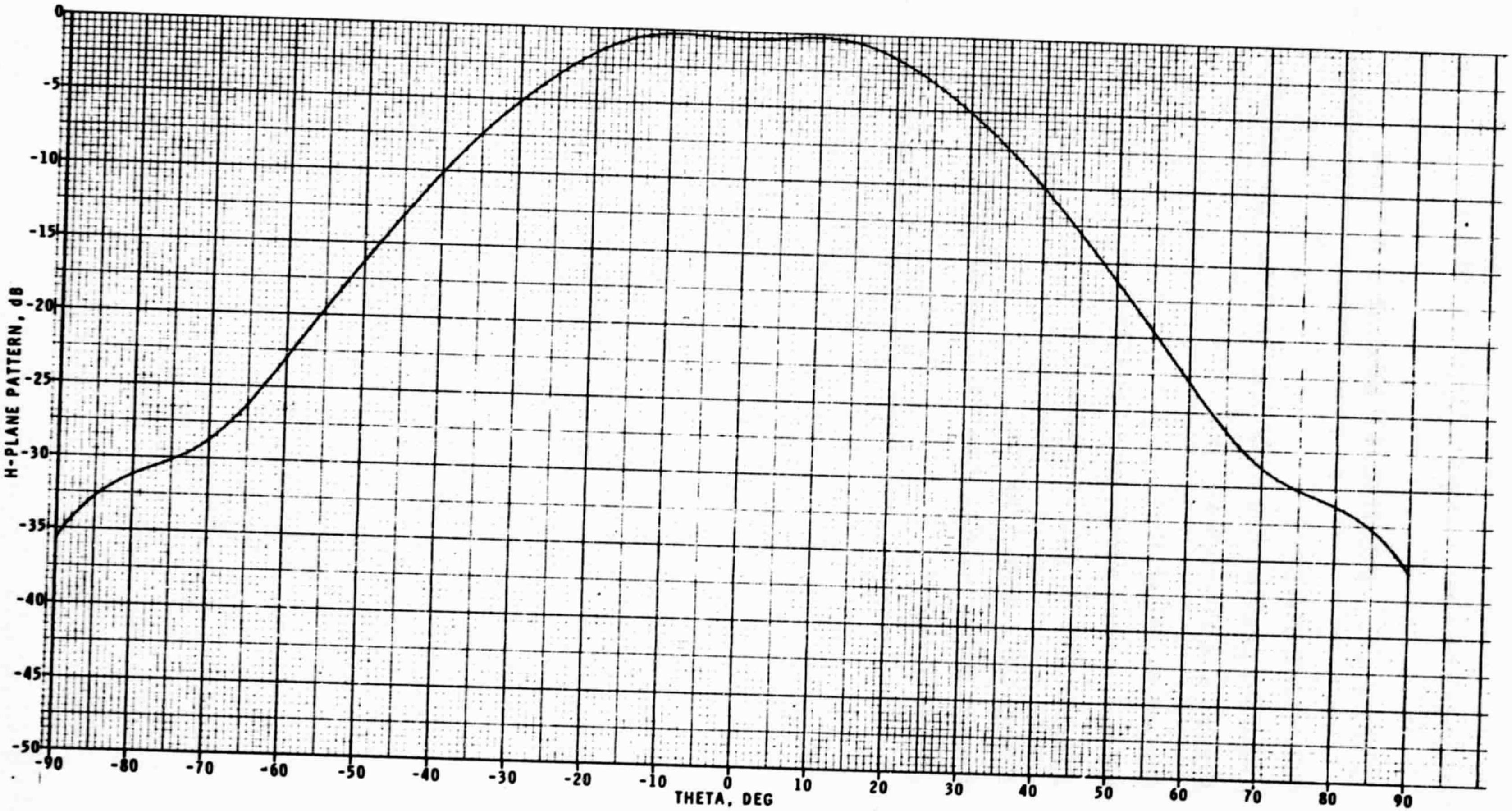

Figure 4-10. H-plane pattern for shaped reflector feed horn (30 GHz).

Table 4-1 gives the specifications for the feed horns.

TABLE 4-1. FEED HORN SPECIFICATIONS

A. Cassegrain System Required beamwidths at 20 and 30 GHz. Specified in Figure 4-2 through 4-5 inclusive.
B. Shaped Beam System Required beamwidths at 20 and 30 GHz. Specified in Figures 4-7 through 4-10 inclusive.
C. Flanges for Both Systems Compatible with Waveguide Circuitry Specification (Table 3-7).

5. DISH REFLECTORS

A. The Cassegrain Paraboloidal Reflector

The paraboloidal reflector and feed system uses a Cassegrain geometry for an antenna that produces concentric pencil beams at the 20 and 30 GHz frequencies. This system consists of a main paraboloidal dish, a conical corrugated feed, and an additional hyperboloidal subreflector, which allows the feed to be positioned for minimum blockage. The basic configuration is illustrated in Figure 5-1.

Design parameters were developed from vector diffraction computer programs. In the calculation of efficiency, the forward spillover and subreflector blockage are taken into account.

The resulting designs, shown in Figure 5-1 and listed in Table 5-1, do not result in the usual high efficiencies associated with Cassegrain antennas. In this case the subreflector was only 5.24 wavelengths in diameter at 20 GHz (7.90λ at 30 GHz). Other designs such as the front fed paraboloidal reflector and the offset reflector were considered. The front fed reflector could have been constructed with: 1) the waveguide circuitry attached to the feed, or 2) with waveguide runs to the sides of the reflector for attachment to the waveguide circuitry. In the first design the asymmetrical aperture blockage by the waveguide would have caused loss of circularity of the signals and some decrease in gain, in the second design extra heat loss in the waveguide runs would have decreased the net gain. The offset fed paraboloid would have increased cross-polarization without any increase in net gain over the Cassegrain system. Thus it is felt that the Cassegrain design resulted in the best gain and polarization purity. The electrical performance is shown in Table 5-2. The estimate of the loss due to surface tolerance

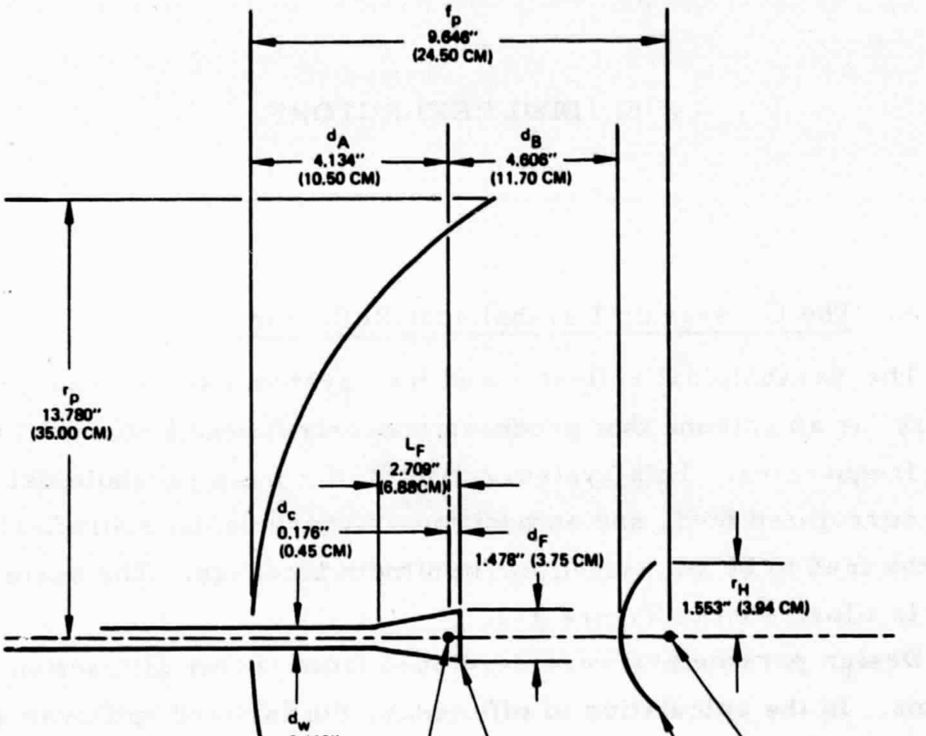

Figure 5-1. The Cassegrain configuration.

TABLE 5-1. PARAMETERS FOR CASSEGRAIN ANTENNA SYSTEM

<u>Paraboloidal Reflector</u>	
Aperture	27.56 inches
Focal length	9.646 inches
Opening in center	3.00 inches
<u>Hyperboloidal Subreflector</u>	
Aperture	3.106 inches
Eccentricity	1.490
Distance from vertex of main dish	8.740 inches
<u>Conical Corrugated Feed Horn</u>	
Aperture	1.478 inches
Flare angle	14.0 degrees
Location of feed phase center	4.134 inches in front of paraboloid

TABLE 5-2. ELECTRICAL PERFORMANCE OF CASSEGRAIN SYSTEM

Frequency, GHz	20	30
Efficiency	0.486	0.699
3 dB Beamwidth	1.38 degrees	0.94 degrees
Area Gain, dB	43.3	46.8
Efficiency, dB	-3.3 (46.7%)	-1.6 (69.2%)
Surface Tolerance Loss, dB	0.1	0.1
Feed Horn Loss, dB (Est.)	0.3	0.3
Net Gain, dB	39.6	44.9
Degradation due to thermal environment	0.2	0.2
Net overall gain, dB	39.4	44.7

will depend on the magnitude of that tolerance. The estimate tolerance was chosen to be 0.003 inches rms (0.10 mm), which is commensurate with the tolerances measured on the Nimbus 31 inch diameter reflector made from an epoxy graphite reinforced fiber.*

B. Shaped Reflector

The reflector system must be specially designed so that the reflector and horn feed produce the illumination required to give the gain curve of Figure 2-1. The problem is separable into the steps of reflector design and pattern verification. The reflector design step uses a method due to Dunbar** and determines a surface curved differently in each of two perpendicular directions. This surface is intended to produce the desired gain curve for a given feed illumination. The second step is to verify that the computed surface will, in fact, yield the necessary gain curve. The resultant pattern is examined to determine whether it meets the requirements. If not, the inputs used in the first step are revised, and the reflector pattern is recomputed.

Reflector design begins with the given feed and secondary patterns in the plane of shaping, called the central-section plane. An initial shape is then chosen as an approximation for the actual reflector surface. This initial surface is parabolic in each of two perpendicular directions (one containing the curve of the central section plane), since this form results in a far-field pencil beam. In one of the perpendicular directions the parabolic form is retained, although the specific parameters of the particular parabolic segment may change as the design progresses. In the plane of the central section curve, however, the parabolic form is distorted into some other curve which will transform the feed pattern into the desired shape. The distortion is obtained by an iterative procedure using the given patterns and the surface approximation. After each iteration the resultant set of numbers,

*Knoell, A., and G. Krumweide, "Structural Development of the Nimbus-G/Seasat-A SMMR Graphite Epoxy Antenna Reflector," to be presented at the Second International Conference on Composite Materials, April 1978, Toronto.

**Dunbar, A. S., "Calculation of Doubly-Curved Reflectors for Shaped Beams", Proc. IRE, October 1948, pp. 1289-1296.

representing a new approximation for the central section curve, is compared with previous values. When agreement is found to be within a specified tolerance, the iterations stop, and the entire surface may be calculated on the basis of the data obtained. Convergence is very rapid, and is proportional to the order of magnitude of the required tolerance.

The second step of the design process is to verify that the computed surface will actually yield the necessary gain curve. The double-curvature surface calculated by the Dunbar procedure is relative to a rectangular grid in a three-dimensional cartesian coordinate system. Second-order interpolation permits the transition to a polar grid in a cylindrical coordinate system. A double integration of the illumination function over the reflected surface generates the secondary pattern. This pattern appears as a function of the angles θ and ϕ of a spherical coordinate system centered at the focus of the reflector. The cut perpendicular to the central section curve shows a pencil beam, as expected. The cut parallel to the central section curve shows the effect of surface shaping. If this cut does not have an acceptably shaped pattern, the "goal pattern" used by the Dunbar procedure may be adjusted, and the design continues until suitable results are obtained.

The initial doubly curved reflector was chosen for a nominal parabola focal length of 14.76 inches, with an f/D of 0.5. The edge of the reflector subtended an angle of 53 degrees from the vertex, measured at the focus. Figure 5-2 shows the basic form of this dish. The conical corrugated horn computer program generated amplitude and phase information for the feed pattern in both E- and H-planes. The amplitude information was used as input data for the Dunbar program. An initial pattern was constructed from the specified antenna gain curve for angles ranging from the beam peak to 70 degrees away (covering the full required range). The peak of the beam was to coincide with the reflector axis. After several trials, the Dunbar program generated the central section contour of Figure 5-3. The shaped dish having this contour produced (at 20 GHz) the curve of Figure 5-4, which has a peak directivity of 34.2 dB and is above required levels for all angles out to at least 70 degrees from the peak. The pencil-beam pattern of

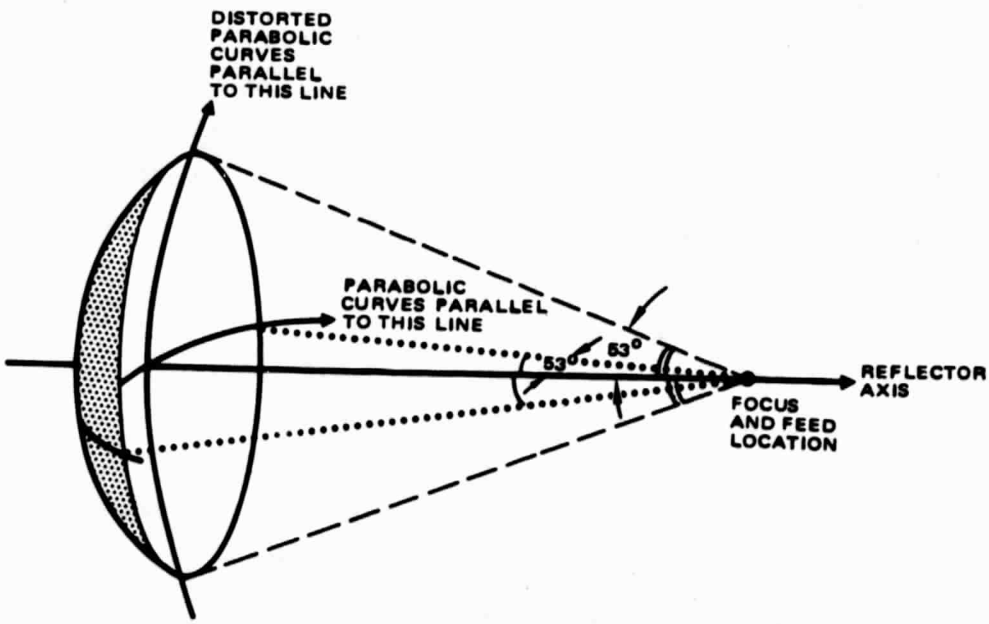

Figure 5-2. Double-curvature reflector.

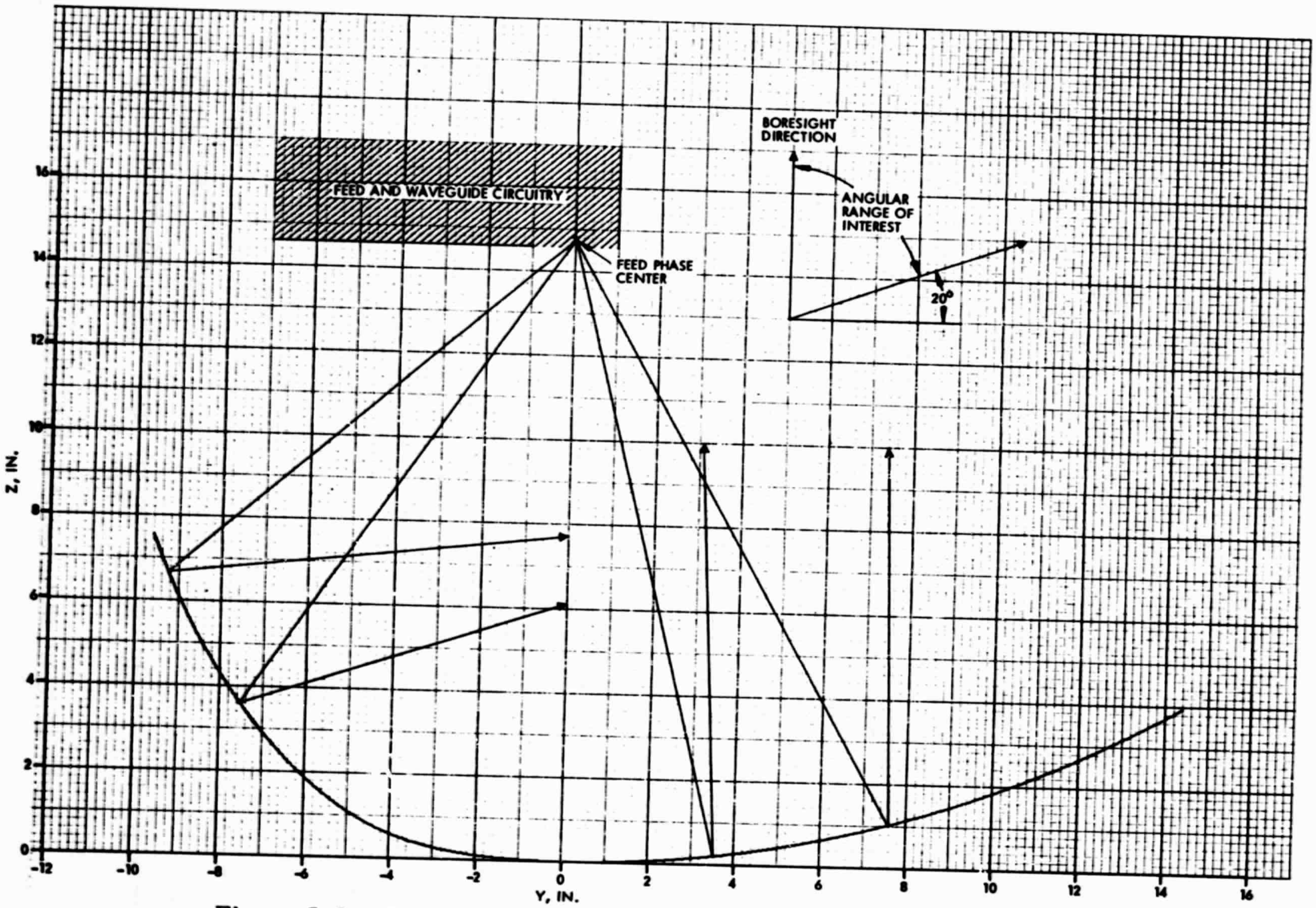

Figure 5-3. Central section contour of shaped reflector.

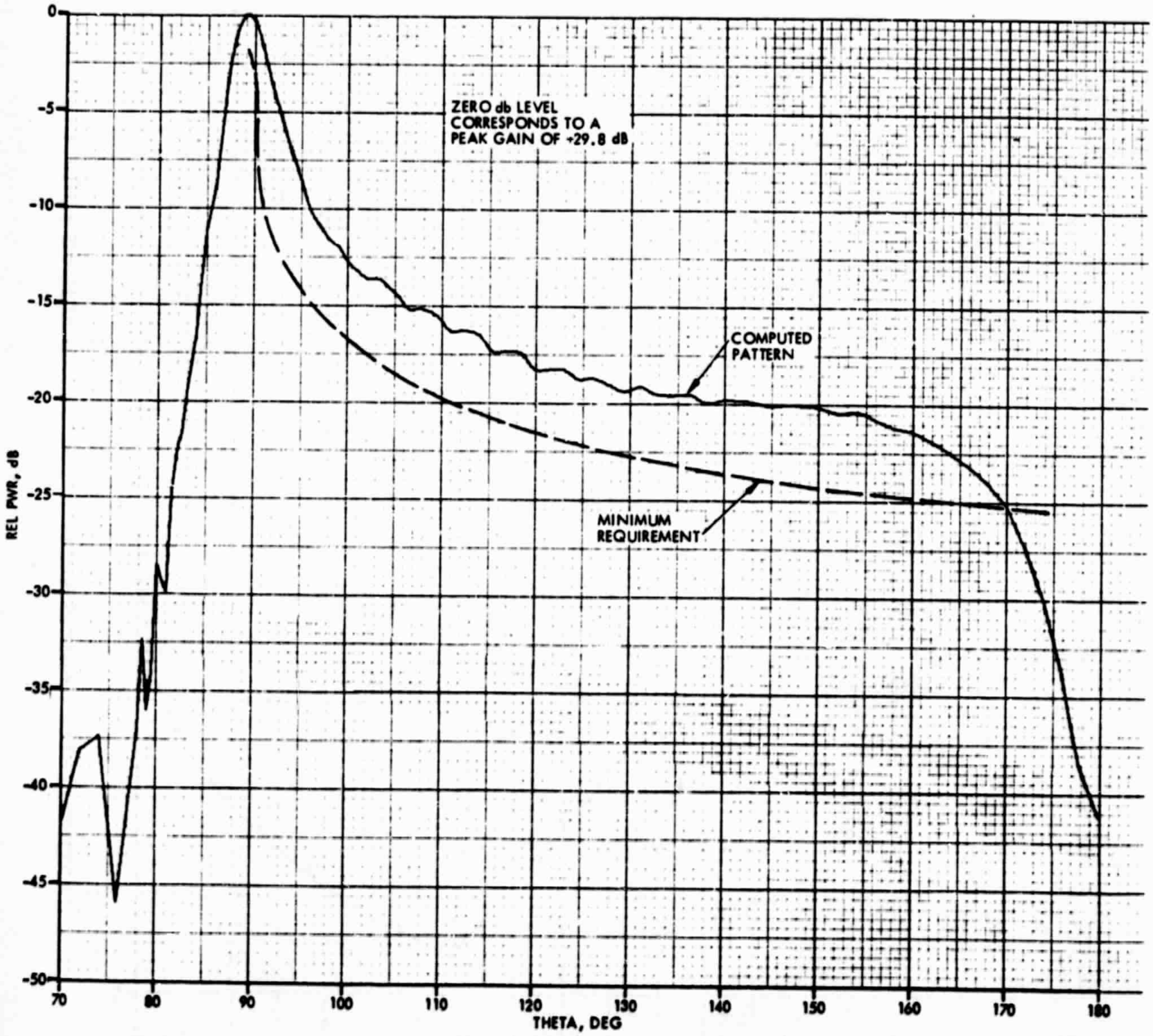

Figure 5-4. Elevation shaped beam pattern (20 GHz).

Figure 5-5 is for a cut passing perpendicularly through the shaped beam at its peak. The antenna performance at 30 GHz is described by Figures 5-6 and 5-7. Peak directivity at this latter frequency is 36.7 dB, and the antenna again satisfies the requirements out to at least 70 degrees from the peak.

The dish is circular in outline, although it is not a surface of revolution. Along the outer edge the height above the lowest point on the

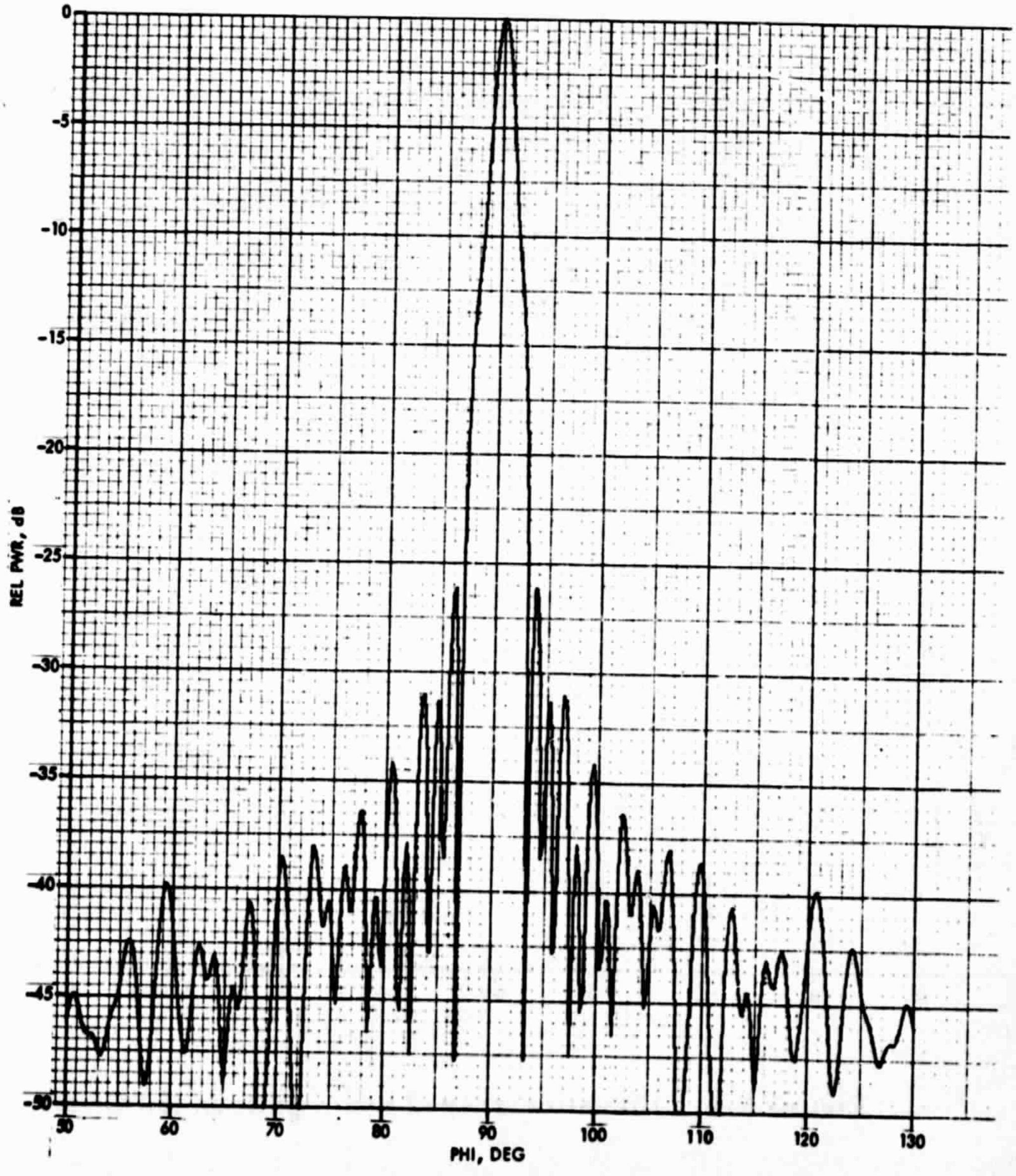

Figure 5-5. Azimuth pattern through peak of beam (20 GHz).

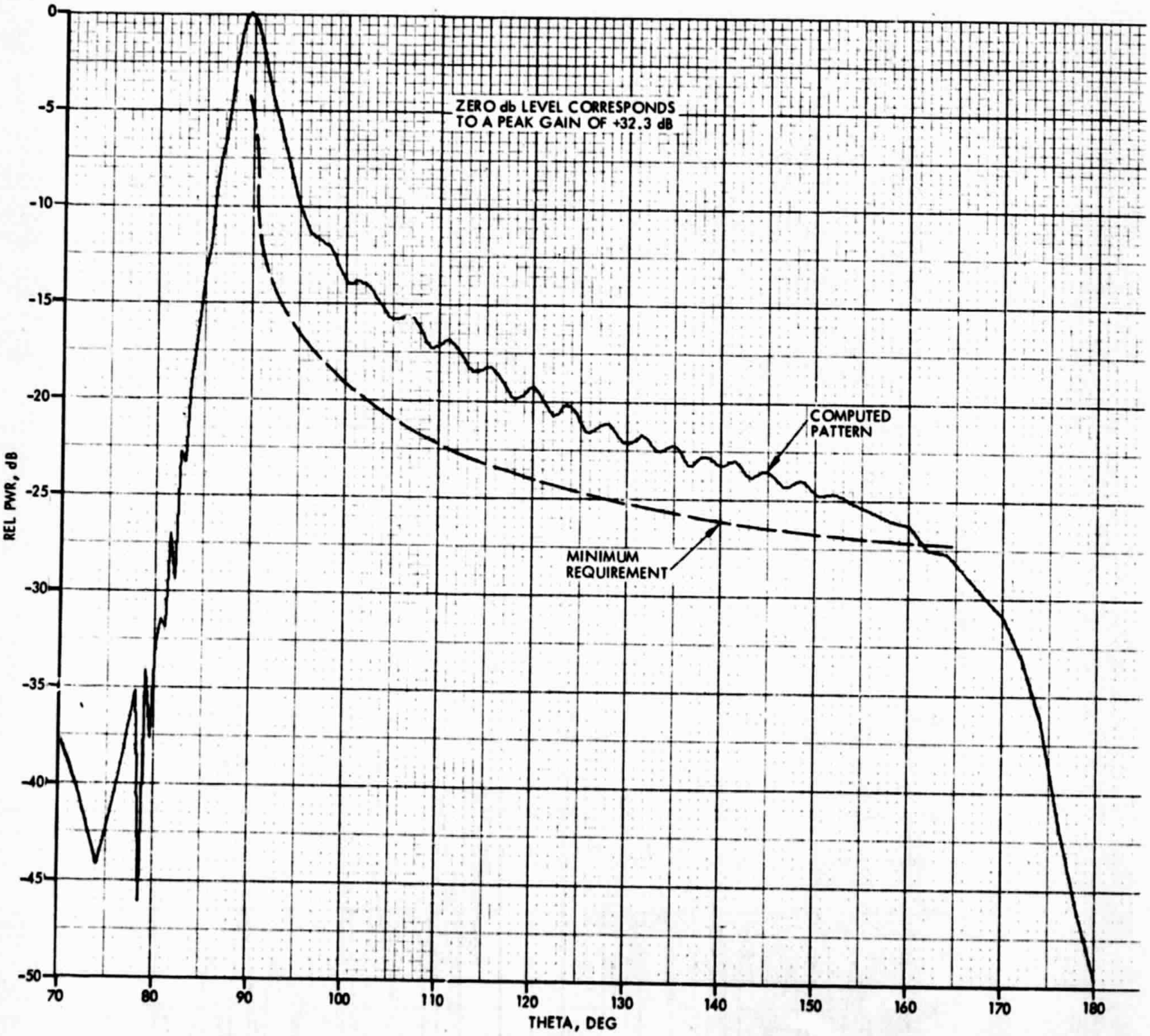

Figure 5-6. Elevation shaped beam pattern (30 GHz).

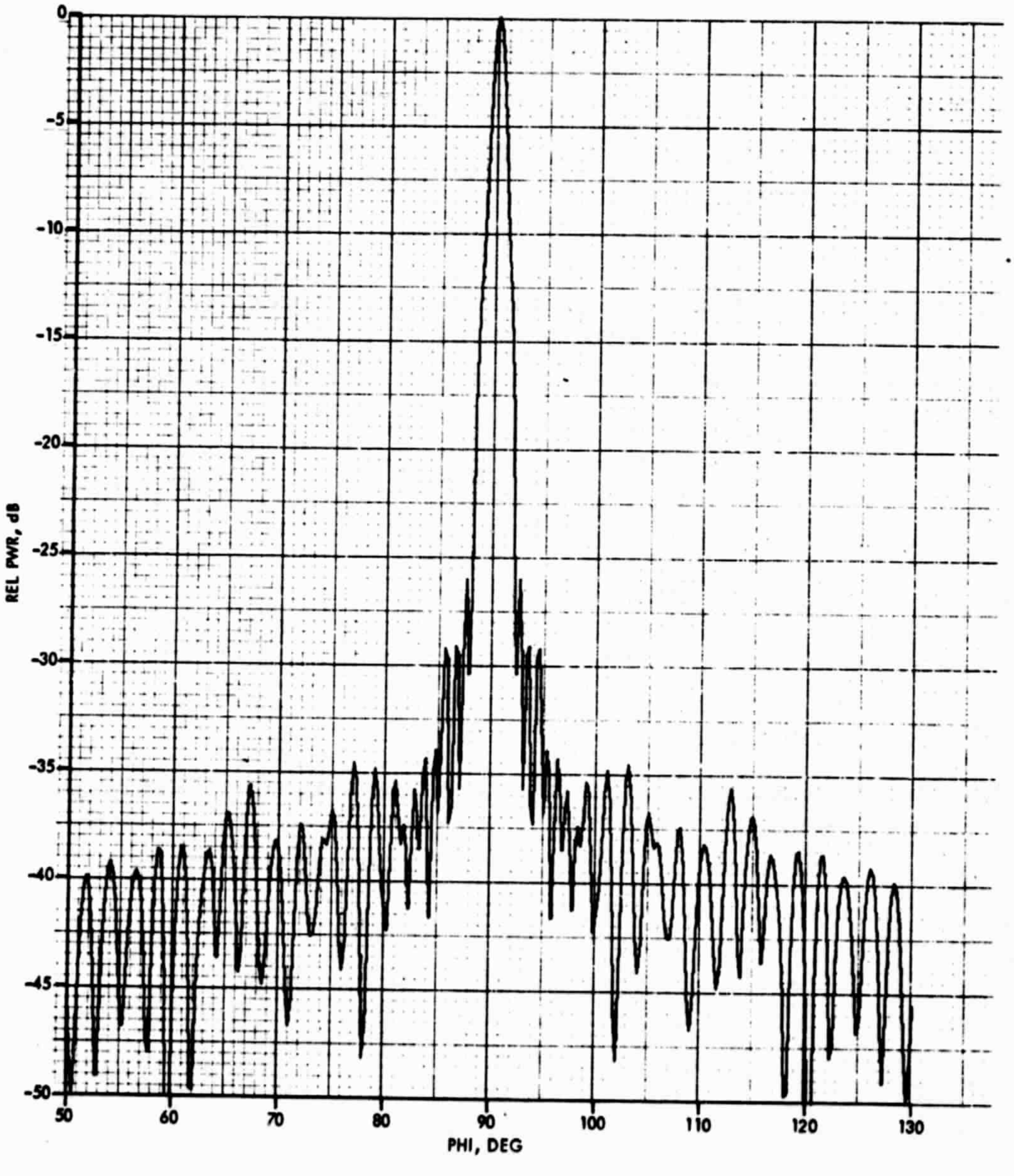

Figure 5-7. Azimuthal pattern through peak of beam (30 GHz).

surface ranges from a minimum 2.25 inches to a maximum 7.50 inches. The corrugated feed horn is located 14.76 inches above the vertex, and is displaced from the center of the dish in the direction of maximum edge elevation by 2.40 inches.

As may be seen from Figure 5-3, the feed and waveguide circuitry are placed almost entirely outside the angular range of operation. Because of this, aperture blockage by these components is not a significant problem. Electrical characteristics are found in Table 5-3.

Table 5-4 summarizes the specifications for the reflectors.

TABLE 5-3. SUMMARY OF ELECTRICAL CHARACTERISTICS OF SHAPED REFLECTOR

Frequency, GHz	20	30
Peak Directivity, dB	34.2	36.7
Efficiency (Est.), dB	-3.0	-3.0
Surface Tolerance Loss, dB	0.1	0.1
Feed Loss, dB	0.2	0.2
Net Peak Gain, dB	30.9	33.4
Beamwidth in Azimuth	1.8 degrees	1.2 degrees

TABLE 5-4. DISH REFLECTOR SPECIFICATIONS

A. Cassegrain Reflector

Design Dimensions – see Table 5-1

Required Performance – see Table 5-2

Overall Design: To be compatible with Shuttle environment. Degradation due to thermal environment less than 0.2 dB in gain including loss due to boresight wander. Reference is the physical interface of experimental package to Shuttle.

Attachment Points – Compatible with gimbal design and feed designs.

B. Shaped Beam Reflector

Design Dimensions: See Figure 5-3

Required Performance: See Figures 2-1, 5-4 and 5-6

Overall Design: To be compatible with Shuttle environment. Degradation due to thermal environment included in required performance specification.

Attachment Points: Compatible with gimbal design and feed designs.

6. GIMBAL SYSTEMS

A. Two-Axis Positioner

The positioner for the Cassegrain paraboloidal reflector consists of a two-axis, servo controlled, rotating mechanical and electrical interface between the shuttle structure and the antenna. The aluminum shaft and housing assembly contains torquers, bearings, encoders, waveguide, and a signal and a power cable as shown in Figure 6-1. Table 6-1 lists the antenna positioning and pointing requirements that are satisfied by this design. Prior to selection of the Ku-Band space shuttle gimbal as the antenna positioner for the MWCE, other configurations such as full yoke, half yoke, and "L" configuration were considered and evaluated. Use of the "T" arrangement for the axes results in a positioner of lighter weight and simpler construction than could be achieved by employing a conventional yoke design for the gimbaling axes. The "T" arrangement is most suitable for containing the waveguide runs within the gimbal since external runs are particularly awkward when two parallel runs are required.

The positioner packaging arrangement is a compact assembly utilizing proven, off-the-shelf type components. The azimuth gimbal housing is fixed relative to the supporting structure and its motor and bearing assembly rotates the inner T-shaped shaft through an angle of ±180 degrees. The elevation motor and bearing assembly rotates the elevation housing (to which the antenna supports are attached) around the upper branch of the T-shaped shaft through an angle of -25 to +90 degrees.

Selection of the more conventional fixed housing, rotating shaft configuration for the inner axis was rejected since it would involve the complexity of exiting the waveguide run between the axes and routing the waveguide to a junction with the inner gimbal rotary joint. Further, the service cables that

TABLE 6-1. ANTENNA POSITIONER REQUIREMENTS AND CHARACTERISTICS

Antenna	Weight Inertia	6 pounds (2.7 kg) 0.6 slug - ft^2 (0.8 kg-m^2)
Services	2 waveguides	20 GHz and 30 GHz
	1 coaxial cable Wires	50 ohm 56
Angles		2-axis $\begin{cases} Az \pm 180^\circ \\ El +90^\circ -25^\circ \end{cases}$
Accuracy		0.4 degree
Rate		1 degree per minute
Redundancy		Not required
Weight for Gimbal		42 pounds (19 kg)
Quality Level		NASA experiment level Military E.R. (established reliability) Parts
Locks		Relatch Lock as now designed
Temperature Range of Environment		-160°F to $+220^\circ$F,[1] (-107°C to 104°C)

(1) Heaters and thermostats are required to maintain the optical encoder and control electronics above zero degrees F.

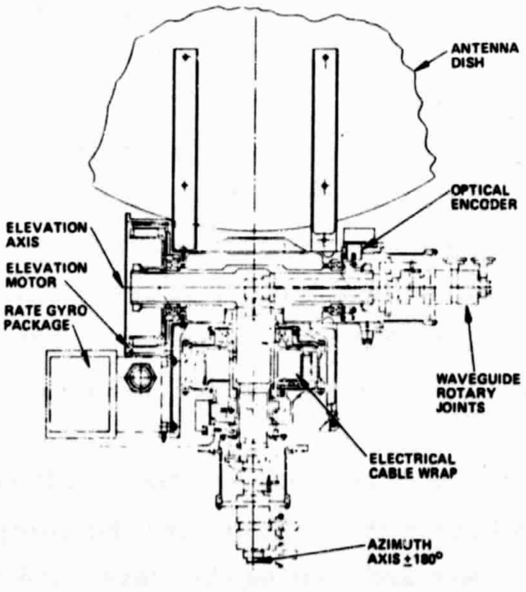

Figure 6-1. Two-axis gimbal assembly.

must cross the axes would have to make a similar exit and have their service loops mounted externally to provide proper gimbal freedom. Handling of this cabling to provide proper support and prevention of tangling would involve several special guides, restraints, and supports that would add significantly to cost.

The T-shaft configuration allows much simpler waveguide, rotary joint, and cable packaging to be used by allowing the whole arrangement to move together across the axis junction. Cabling entering the outer gimbal structure has its service loop contained within the inner cavity of the azimuth motor. Passing through the axis junction, the service cable leaves through the open end of the shaft where the elevation axis relative motion is absorbed by the service loop between the elevation shaft exit and the antenna.

The gimbal components will be identical to those used in the Ku-Band system since there will be significant cost savings. The torquer motor is larger and has far more torque than required, but will be used since the gimbal structure is already designed for the larger size, and the circuits for the motor driver are already designed for the actual resistance and torque constant. The position readout and cabling systems are also usable. The waveguide, however, must be changed to meet the frequency requirements; the same rotary joint approach will be used as developed for the Ku-Band system. The selected motors are full rotation, brush type, permanent magnet, torque motors. Motors are sized to provide adequate torque in each axis for the spiral scan accelerations during the radar scan of the Ku-Band system plus an adequate margin for bearing torques and cable torque variations over the full temperature range. The motors have the following characteristics: 1) 6.25 ft-lb peak torque; 2) 6.6 ohm resistance; 3) the motor constant (K_M) is 0.667 ft-lb $\sqrt{W}$ (or 0.904 nt-m $\sqrt{W}$), where W is in watts.

The precision angular contact bearings in each axis support the gimbal. The angular contact bearing pairs are mounted in a back-to-back configuration to provide the greatest effective separation and, therefore, the most favorable moment arm. Dry films provide a very uniform operation over a wide temperature range. Hughes has developed a sputter plating technique that provides a very thin film of tightly adhered dry lubricant that, with the absence of any binder, does not alter the internal geometry of the bearing. The resultant bearing is extremely smooth running and has excellent wear life; it is compatible with a space environment near optical surfaces.

The position control electronics provides for the incremental positioning of the experiment sensor in an azimuth and elevation coordinate system. The actual sensor pointing angles are stored in 12 bit up-down counters which are incremented in response to the shaft angle encoder pulses. The desired angles are stored in similar counters which can be incremented up or down by the four input command pulse lines. The difference between the desired and actual angles is computed by digital subtraction to produce pointing error signals which are converted to analog voltages, amplified and shaped for best accuracy and stability before being used to command positioner torque via the motor drivers. All four counters are initialized whenever the positioner is stowed and locked. The positioner is returned to stow position by sending enough additional command pulses to make the up and down pulses equal. A tachometer circuit ensures that the gimbal turning rate will never exceed 100 degree/second by turning off the motor driver if excessive speed is detected. The azimuth and elevation torque motor drivers, the stow motor driver, and the encoded processors are identical to those used on the Ku-Band system. Simple integral plus lead shaping is implemented with analog circuits. A simplified block diagram is shown in Figure 6-2.

A low-cost, modular, incremental encoder is incorporated in each axis to provide digital position information for command and data use and to provide feedback for position rate of change. The device consists of an extremely reliable LED source photo transistor sensor assembly and an etched chrome grid or a slotted disk and hub assembly that mounts directly on the shaft and the housing. The LED and photo transistor are readily available in qualified JANTX (Joint Army Navy Extra Test) parts. This proven device provides direct digital output of sufficient granularity (0.176 degree basic; 0.088 degree with processing), direction indication, and a master index pulse for register initialization. The digital output is compatible with the control system electronics and requires less complex

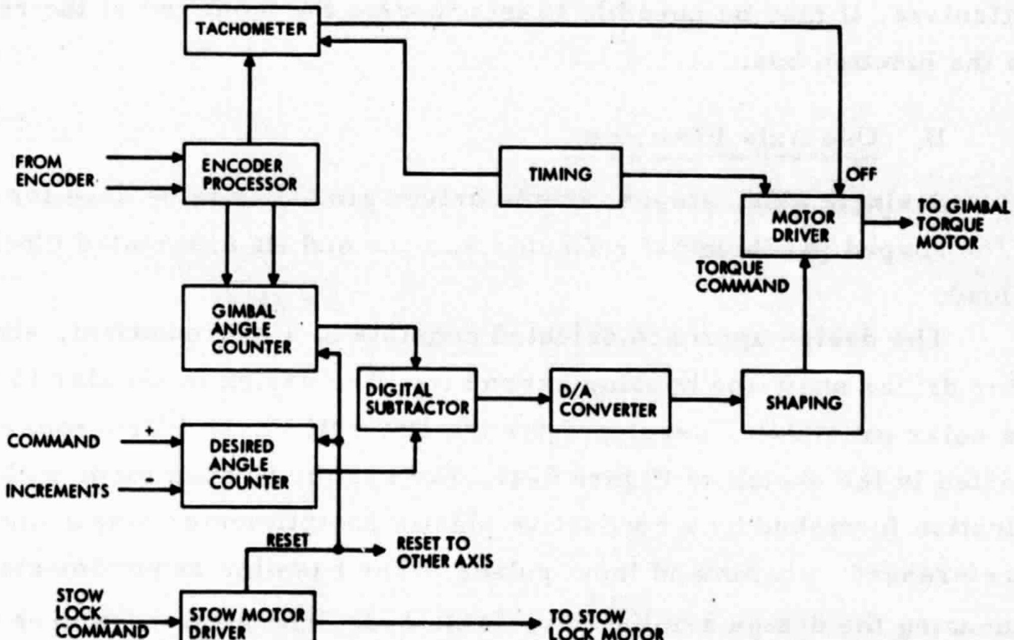

Figure 6-2. Position control (one axis shown).

circuitry than a resolver. Use of an incremental output rather than absolute position output results in a less costly unit with fewer lead wires and avoids the ambiguity associated with the outer axis angular range being greater than 360 degrees to ensure a 360 degrees total operating range.

The two axis system with attached antenna is shown in Figure 6-3. The junction box is used to connect the dual waveguides issuing from the rotary joint to the waveguide network components. Depending on design particulars, it may be possible to incorporate the front end of the receiver into the junction box.

B. One Axis Positioner

A single axis, stepper motor driven gimbal is to be used for positioning the shaped paraboloidal reflector antenna and its associated electronic payload.

The design approach selected consists of a nonredundant, stepper motor driven shaft and housing assembly. The design is similar to the single axis solar panel drive developed for the DSCS III Phase I Program and is depicted in the sketch of Figure 6-4. The system is open loop, with position indication furnished by a conductive plastic potentiometer output which can be referenced to command input pulses. The baseline requirements influencing the design are listed in Table 6-2. The gimbal features and characteristics are presented in Table 6-3. Figure 6-5 pictures the antenna system attached to this gimbal.

To extend this gimbal to a two-axis system, it is sufficient to add a second (elevation) axis capability to the gimbal; the design is such that an identical drive unit (and duplicate electronics drive box) can be added to the existing gimbal by incorporating some adaptive hardware, thus minimizing the nonrecurring costs associated with the implementation.

The gimbal specifications are listed in Table 6-4.

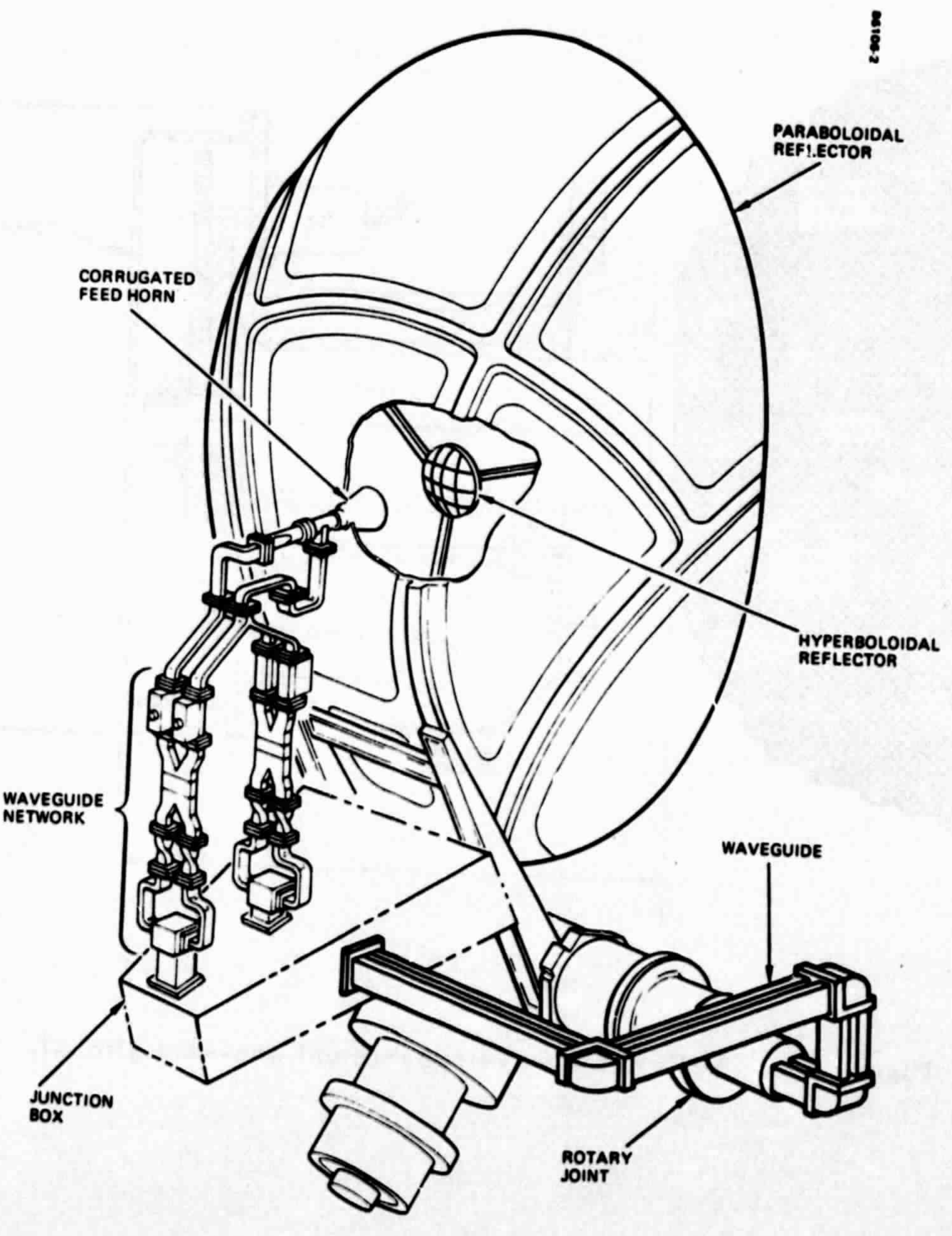

Figure 6-3. Two axis gimbal assembly with attached antenna.

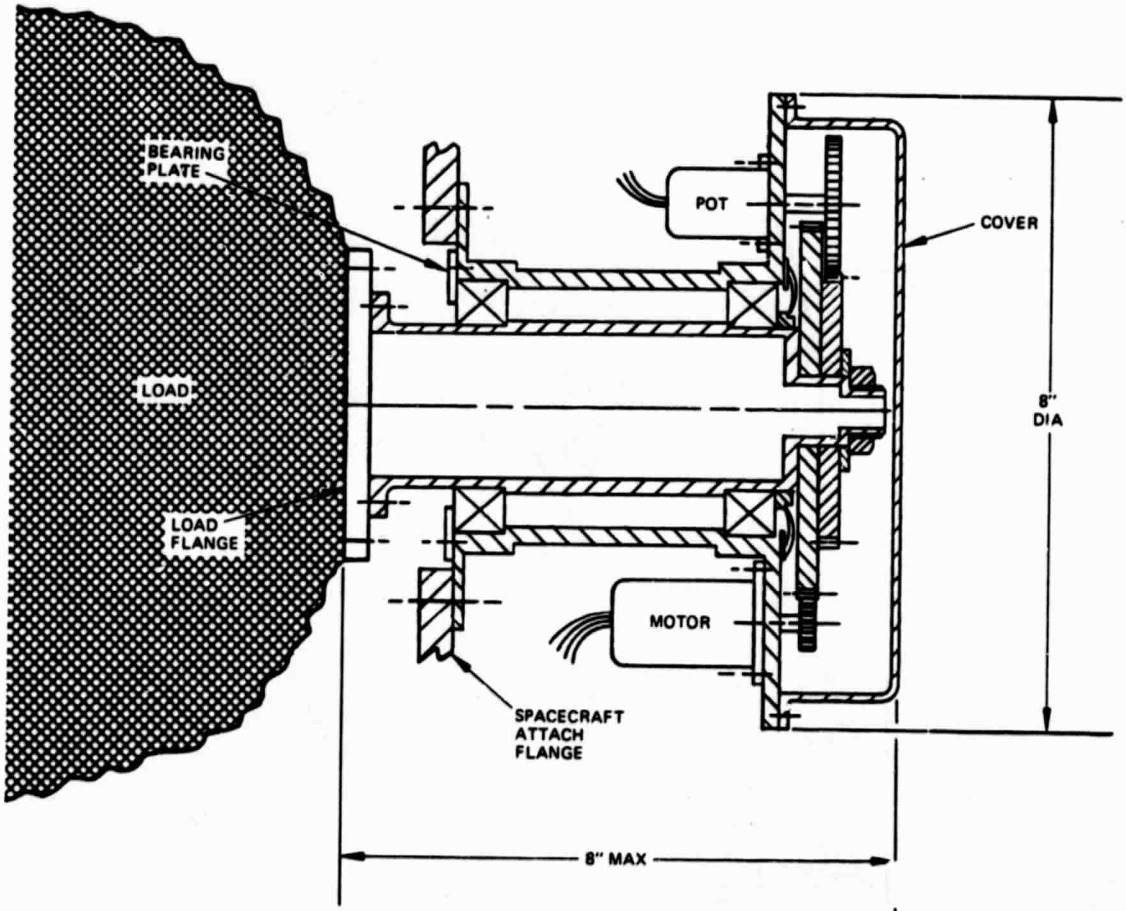

Figure 6-4. Millimeter wave experiment one-axis gimbal.

TABLE 6-2. MILLIMETER WAVE EXPERIMENT ONE-AXIS GIMBAL REQUIREMENTS

Antenna	Weight – 6 pounds (2.7 kg) Inertia – 0.6 slug-ft^2 (0.8 kg-m^2)
Payload	Weight – 50 pounds (23 kg) Inertia – 0.4 slug-ft^2 (0.5 kg-m^2)
Services	Power and signal wires
Motion	Single Axis – ±90 degrees
Drive	Stepper Motor – Nonredundant
Rate	<3 degrees per minute
Resolution	<1 degree
Accuracy	<1 degree
Life	7 days at 16 orbits/day
Quality Level	NASA experiment level Military ER parts
Temperature range	-160°F to +220°F (-107°C to 104°C)

TABLE 6-3. MILLIMETER WAVE EXPERIMENT ONE-AXIS GIMBAL FEATURES AND CHARACTERISTICS

- Single axis
- Stepper motor drive
  - Size 23 — 1.8 degrees PM stepper
  - Single stage 6:1 gear reduction
  - Rate — 1 pps — equivalent to 18 degrees/minute output rate
  - Step increment — 0.3 degree per step
- Position indication — conductive plastic potentiometer
  - 1.8:1 ratio — ~324 degrees of pot travel for ±90 degrees output
  - Accuracy ±0.45 degree (0.25 percent linearity)
- Angular contract, preloaded shaft/housing bearings
  - Sputtered MoS_2 lubrication
- Power dissipation — ~15 watts (when pulsing)
- Torque margin — 4.5:1 (cables, friction, inertia)
- Weight estimate — 6.5 pounds (2.95 kg)
- Volume — 8 inches diameter by 8 inches long (20.3 by 20.3 cm)

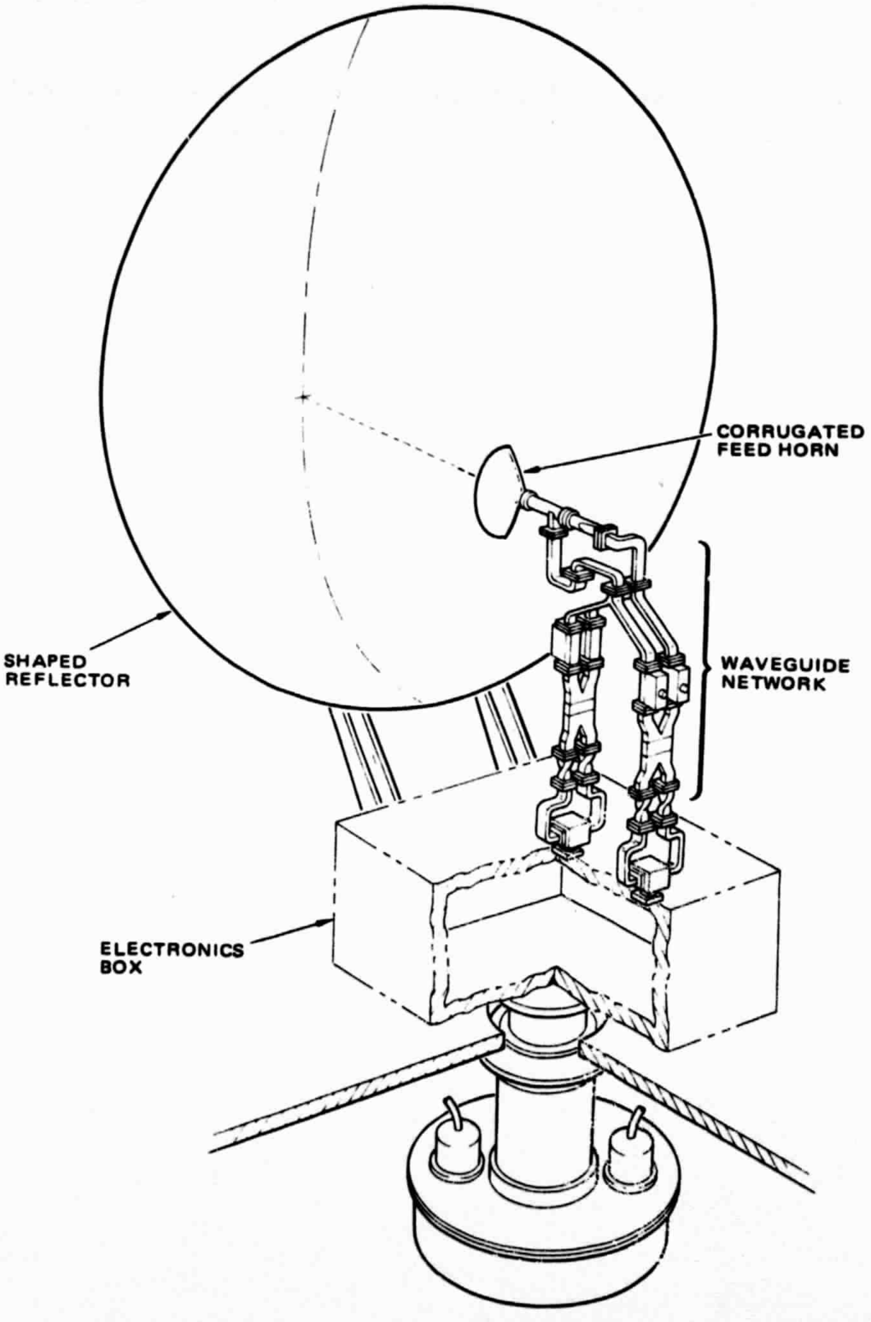

Figure 6-5. One-axis gimbal assembly with attached antenna.

TABLE 6-4. GIMBAL SPECIFICATIONS

A.	Two Axis Positioner for Cassegrain System – See Table 6-1
B.	One Axis Positioner for Shaped Beam System – See Table 6-2

7. SUMMARY OF SYSTEM DESIGNS

From the initial feasibility study, two antenna systems were selected for further definition: 1) a Cassegrain paraboloidal reflector system positioned by a two axis gimbal system, and 2) an offset front fed shaped reflector with a single axis positioner.

The Cassegrain system offers higher gain with increased cost and complexity in the positioner system. The positioner is a modified version of the one used in the Shuttle Ku-band Communication and Radar Rendezvous system. It can be used for autotrack if required. The electrical performance is shown in Table 7-1.

TABLE 7-1. TWO AXIS CASSEGRAIN SYSTEM

Frequency, GHz	20	30
Antenna Gain, dB	39.6	44.9
Rotary Joint Losses, dB	0.5	0.5
Waveguide Losses, dB	0.5	0.5
Waveguide Feed Network Loss, dB	0.9	0.9
Thermal Degradation, dB	0.2	0.2
Antenna System Gain, dB	37.5	42.8

Figure 7-1 shows the integration of the two-axis system into the Spacelab/Shuttle pallet. Figure 7-2 indicates the pallet equipment.

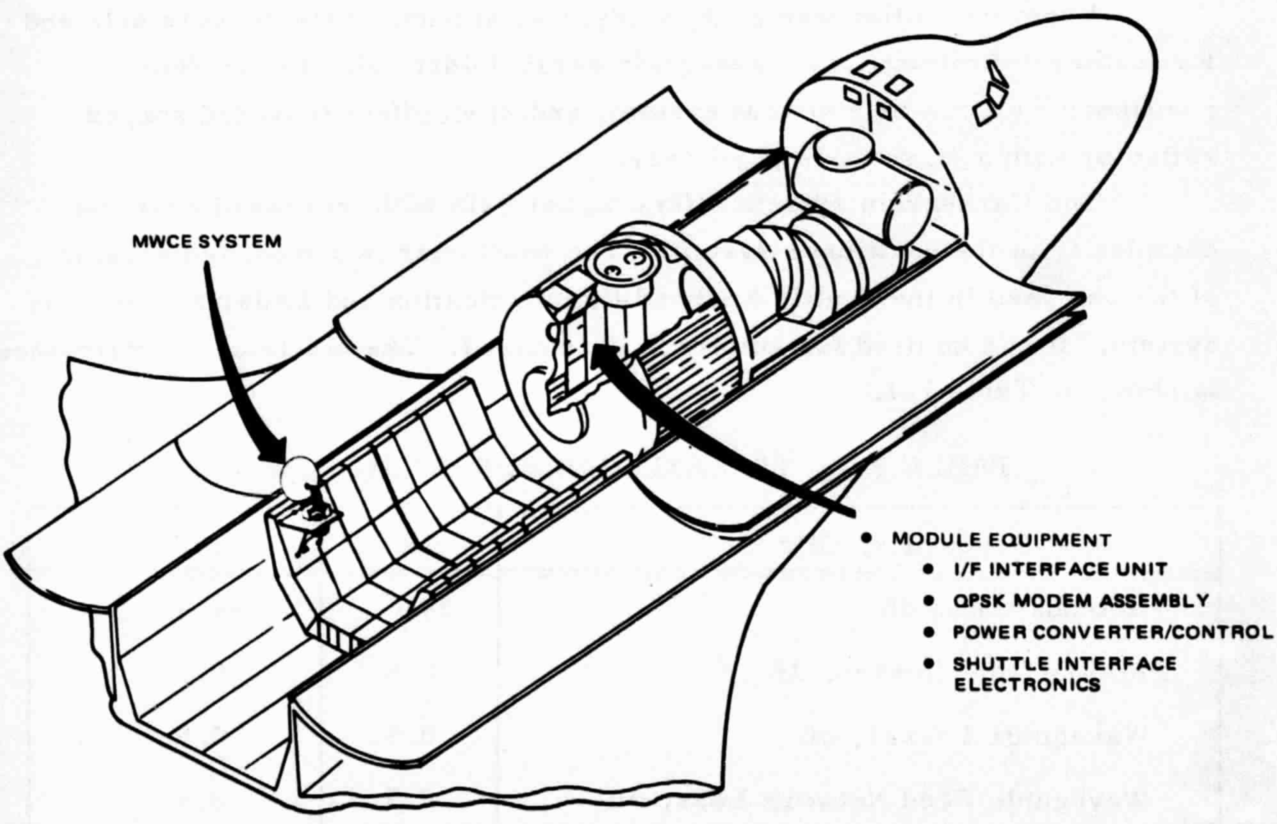

Figure 7-1. Concept of two-axis Cassegrain system installed in Spacelab/Shuttle.

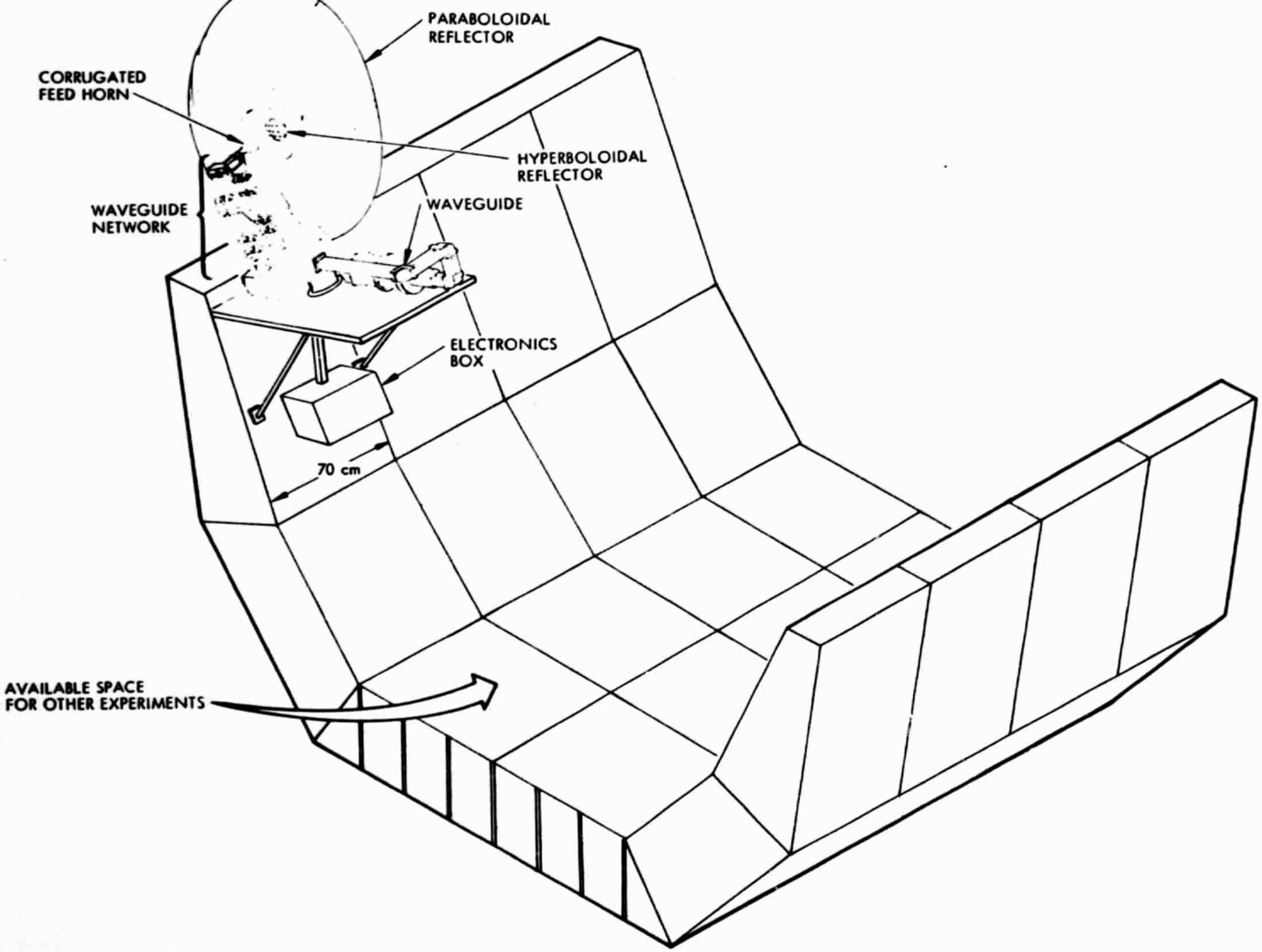

Figure 7-2. Two-Axis Cassegrain pallet equipment

The shaped reflector offers a simple one axis gimbal system with low initial cost. Since the electronics and the antenna are carried on the gimbal, no rotary joints are used. An extension of this system to a two axis positioner has been examined briefly and appears feasible at an additional modest cost since only a duplication of the electronics and interfacing hardware would be needed. Table 7-2 shows the expected performance.

TABLE 7-2. SHAPED REFLECTOR SYSTEM

Frequency, GHz	20	30
Peak Antenna Gain, dB	30.9	33.4
Rotary Joint Loss, dB	—	—
Waveguide Losses, dB	0.2	0.2
Waveguide Feed Network Loss, dB	0.9	0.9
Peak Antenna System Gain, dB	29.8	32.3

Figure 7-3 shows the shaped reflector system integrated into the Spacelab/Shuttle. Figure 7-4 indicates the pallet equipment.

Table 7-3 references the layouts of the two systems and references the applicable documents for the missions.

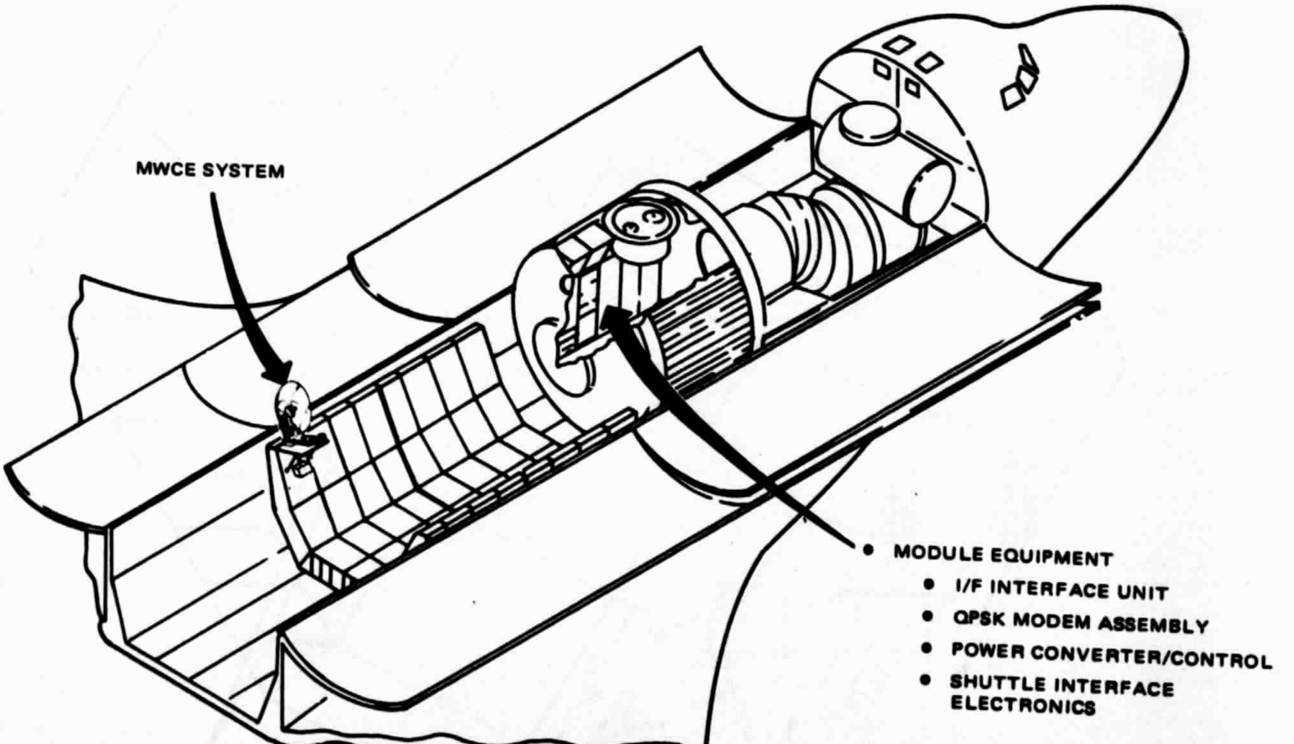

Figure 7-3. Concept of the shaped reflector system installed in Spacelab/Shuttle.

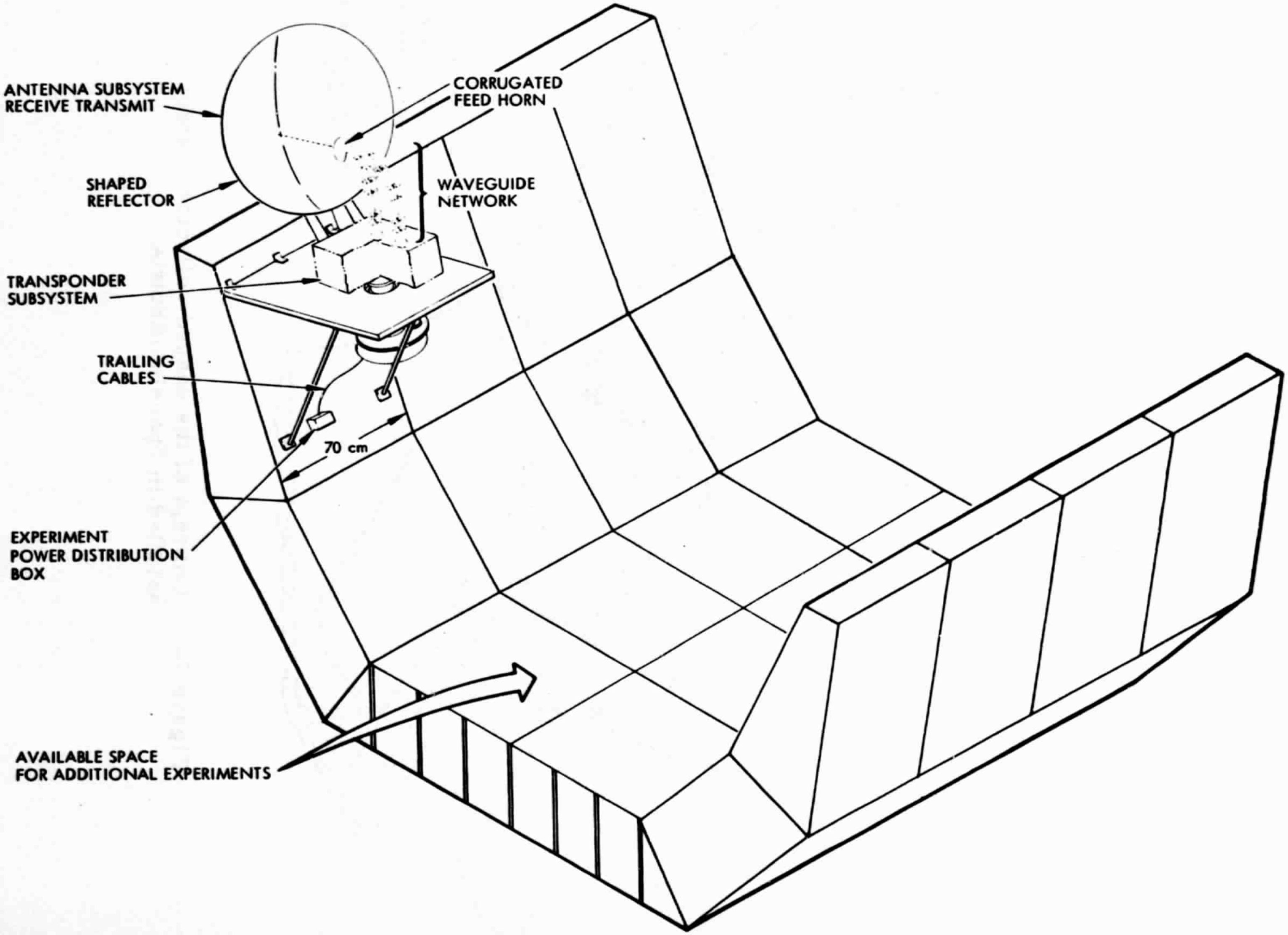

Figure 7-4. Shaped reflector system pallet equipment

TABLE 7-3. OVERALL SYSTEM LAYOUTS AND APPLICABLE DOCUMENTS

A. Cassegrain System – See Figure 6-3

B. Single Axis System – See Figure 6-5

C. Applicable Documents for Subsystems and Overall System Designs

1. MIL-STD-810 Environmental Test Methods
2. JSC-07700, Vol. 14 Space Shuttle Specs – System Payload Accommodations
3. S-320-G-1 General Environmental Test Specifications for Spacecraft and Components, October 1969
4. X-325-67-70 GSFC Magnetic Field Restraints for Spacecraft Systems and Subsystems;

   X-325-71-488 Supplements – Subsystems

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AEROSPACE GROUPS
RADAR SYSTEMS GROUP
CULVER CITY, CA 90230

In Reply Refer To:
78-21-17954/E0522

20 July 1978

SUBJECT: Submittal of Final Report
Shuttle Millimeter Wave Communications
Experiment (MWCE) Antenna System
Contract No. NAS5-24277

TO: National ~~Aeronautics and Space Ad~~ministration
ATTN: Mr. L. J. Ippolito, Code 953
Building 19, Room 4
Goddard Space Flight Center
Greenbelt, Maryland 20771

REFERENCE: Item 4b (Task 3)

1. In accordance with the referenced contract item, enclosed are twenty-five (25) copies of the subject report completing our contractual requirements under the subject contract. Additional distribution has been made as per the contract and are noted below.

2. Delivery of these final reports constitute final end item delivery under the subject contract. Please sign and return one (1) copy of this letter to me indicating your concurrence that all delivery requirements have been completed.

3. If any additional information is required, please contact the undersigned at the above letterhead address or by telephone at Area Code 213, 391-0711, extension 3042.

HUGHES AIRCRAFT COMPANY

E. B. Smith Jr.

E. B. Smith, Jr.
Contract Administrator
Engineering Division Contracts

This will confirm that all delivery requirements have been completed

Signature, Title, Date

EBS:dbc

Enclosure a/s

cc: GSFC-Code 269 (w/encl.)
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